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VOL. XI, PART IV

(August 1941)

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal.

ORIGINAL ARTICLES

THE DESCRIPTION OF CROP-PLANT CHARACTERS AND THEIR RANGES OF VARIATION

BY

B. P. PAL

AND

MEMBERS OF A SPECIAL SUB-COMMITTEE

WITH A FOREWORD

BY

W. BURNS

FOREWORD

FOLLOWING up discussions in the Advisory Board of the Imperial Council of Agricultural Research for India in 1936-37, two committees were formed, one for cotton and one for rice, whose labours resulted in the description of the characters of these crops and their range of variation*. These attempts to prepare schedules to standardize the description of crops have received appreciation from various quarters.

Regarding ' Variability of Indian Cottons ' an American cotton geneticist wrote :

' We must admit that the publication will be of value to us and we shall be using it as a sort of manual or guide in our introduction work where we are attempting to get together an extensive collection of cottons and to classify them taxonomically and morphologically and to make studies regarding their behaviour under our conditions. Thus, we are very grateful to you for the many excellent ideas suggested in your Journal article.'

Mr Hutchinson, who was the moving spirit in the preparation of the cotton publication, expressed the hope that this appreciation would encourage the Council to proceed with similar studies on India's other important crops.

The Imperial Council decided to attempt a similar publication on wheat and, for this purpose, appointed a committee consisting of the following members :

- Dr B. P. Pal (Chairman), Imperial Economic Botanist ;
- Mr K. Ramiah, Geneticist, Institute of Plant Industry, Indore ;
- Rai Bahadur Dr K. C. Mehta, Professor of Botany, Agra College, Agra ;
- Rao Sahib Ch. Ram Dhan Singh, Cerealist, Punjab ;
- Dr B. L. Sethi, Economic Botanist for Cotton and Rabi Cereals, United Provinces ;
- Rao Sahib K. I. Thadani, Director of Agriculture, Sind.

*Hutchinson, J. B. and Ramiah, K. (1938) : ' The description of crop-plant characters and their ranges of variation. I. The variability of Indian cottons. II. Variability in rice.' *Ind. J. Agric. Sci.*, Vol. **8**, pp. 567-616

The basis for this publication was a detailed note prepared and circulated by Dr B. P. Pal and later on revised by him in the light of suggestions received from members of the Committee. The Committee met in Simla in June 1940.

The Appendix on 'Quality in Wheat' was kindly prepared by Rao Sahib Ch. Ram Dhan Singh.

The drawings and photographs were prepared at the Imperial Agricultural Research Institute by Mr K. M. Dhar and Mr S. C. Ghosal respectively, under Dr B. P. Pal's supervision.

In the collection and checking of data for the preparation of the note, Dr Pal was assisted by Mr S. Z. Hasanain, Wheat Breeding Assistant, and by Messrs Harbhajan Singh and H. C. Mirchandani, post-graduate students, and in the examination of wheat material by Mr Habibur Rahman Khan, Fieldman.

It is hoped that this publication will be as useful as its two predecessors and will afford a convenient system for the description of wheat varieties in such a way that easy comparison of types emanating from different areas and breeders will be possible.

W. BURNS
Agricultural Commissioner
with the Government of India

September 13, 1940

III. THE VARIABILITY OF INDIAN WHEATS

(Received for publication on 23 July 1940)

(With Plates XXI-XXX)

MATERIAL TO BE DESCRIBED

THE wheat material to be described may be said, broadly speaking, to be of two kinds, one composed of varieties of commercial importance (these may be old varieties or improved varieties evolved by the departments of agriculture in India) and the other consisting of the large numbers of varieties and hybrid derivatives which are maintained at the main breeding stations for purposes of hybridization or for exchange with breeders in other centres. While the former is likely to be small in number, the latter, as pointed out by Hutchinson and Ramiah [1938], is likely to include hundreds or even thousands of pure lines, and they have recommended that, whereas the descriptions of varieties of commercial importance 'should be as elaborate and as detailed as possible, the description of the type collections will have to be simpler and should be considered mainly from the genetical point of view'.

In view of the general similarity of the wheat material to be described to the rice material dealt with by Hutchinson and Ramiah, it is not necessary to discuss the former in great detail. The recommendations of the authors relating to strains obtained from other provinces, and in particular the desirability of retaining the original names or numbers in such cases apply also to wheat.

SPECIES OF WHEAT CULTIVATED IN INDIA

Five species of *Triticum* are cultivated in India, namely :—

T. dicoccum Schübl.

T. durum Desf.

T. turgidum L.

T. sphaerococcum Perc.

T. vulgare Host

In order to appreciate the position of the Indian wheat species it is necessary to consider briefly their relation to the wheats of the world. As is not uncommon with taxonomic problems, there has been considerable divergence of views regarding the classification of wheats. Accounts of the history of classification have been given by Percival [1921], Clark and Bayles [1935], etc.

The consensus of modern opinion appears to agree on the recognition of the following groups and species. The distinguishing characteristics of these species are well known, and it has not been considered necessary to describe them here.

Group I (Einkorn group ;	$2n$ = 14 chromosomes)
Wild :	*T. aegilopoides* Bal.
	T. Thaoudar Reut.
Cultivated :	*T. monococcum* L.

Group II (Emmer group; $2n = 28$ chromosomes)

Wild :	*T. dicoccoides* Körn.
	T. Timopheevi Zhuk.*
Cultivated :	*T. dicoccum* Schübl.
	T. durum Desf.
	T. persicum Vav.
	T. orientale Perc.
	T. pyramidale Perc.
	T. Polonicum L.
	T. turgidum L.

Group III (Bread or *vulgare* group; $2n = 42$ chromosomes)

Wild :	Nil
Cultivated :	*T. vulgare* Host
	T. compactum Host
	T. sphaerococcum Perc.
	T. Spelta L.
	T. Macha Dek. et Menab.
	T. Vavilovi Jakubz.

The grouping of the wheat species into three groups is a natural one based not merely on the chromosome numbers but is supported by serological studies [Zade, 1914] and studies of susceptibility of the species to certain disease-causing fungi [Vavilov, 1914]. Sax [1921] found that the size of the pollen grain is likewise different in the three groups. The species within any one group are fertile *inter se* but show varying degrees of sterility when inter-crossed.

It will be observed that of the five species of wheat cultivated in India, the first three belong to the Emmer group with the chromosome number $2n = 28$ and the remaining two to the Bread group with the chromosome number $2n = 42$. In general the wheats belonging to the former group possess a higher degree of resistance to some of the more important diseases of wheat than those of the second group. Thus *T. dicoccum* includes some of the most rust-resistant wheats known, *T. persicum* is immune or nearly immune to attack by mildew and *T. Timopheevi* is reported to be highly resistant to all fungous diseases. The transference of the genes for disease-resistance from wheats of the Emmer group to those of the Bread group by breeding is, however, not simple, because of the sterility which is often encountered when such crosses are made. Even when the sterility is not complete, the subsequent segregation of characters may be complex and irregular, rendering difficult the achievement of the combinations desired. The task, however, is not an insuperable one, for some striking successes have been already obtained, for example, the production of the highly rust-resistant variety, Hope, from a cross between the well-known *vulgare* variety, Marquis, and Yaroslav Emmer.

T. monococcum

T. monococcum, the only cultivated member of the first or Einkorn group, is not represented in India. It is also reputed to be highly resistant to diseases.

Notes on the distribution of the five species are given below.

T. dicoccum

The largest proportion of this species is grown as an irrigated crop in Bombay. It is also cultivated to a small extent in Hyderabad (Deccan),

* *T. Timopheevi* is placed by some authors separately in a fourth group

Mysore, Madras and the Central Provinces. The common trade name almost everywhere in South India is *khapli*. In Madras it is also called *samba*, while in Hyderabad the common trade description is *jod gahu*.

T. durum

Durum or macaroni wheats are met with in all the wheat-growing regions of India and commercially this is, next to *T. vulgare*, the most important species. The most extensive areas of cultivation are in the Central Provinces, Bombay, Central India and Rajputana, and Hyderabad (Deccan).

In the trade the wheats of this species are designated by a large number of trade names including *bansi*, *bakshi*, *jalalia*, *malvi*, *kathia*, *haura*, *wadanak*, etc.

T. turgidum

While, according to Howard and Howard [1909], undoubted Rivet wheats have been found in India in Baluchistan only, varieties of this species are to be found occasionally in Central India. These are not of commercial importance.

T. sphaerococcum

This species, according to Percival [1921], is endemic to India and to Iran. According to Howard and Howard [1909], dwarf wheats belonging to *T. compactum* are found in the south-west of the Punjab and, to a smaller extent, in the Central Provinces and the United Provinces. Percival, however, believes that the *compactum* wheats referred to by Howard and Howard belong to *T. sphaerococcum* and that *T. compactum* is not found in India. In a recent paper, Ellerton [1939] states that *T. sphaerococcum* is found in Sind and eastern Baluchistan also.

T. vulgare

This is by far the most important wheat species and embraces the greater portion of the wheats grown in India. The trade names include *sharbati*, choice white Karachi, *pissi*, *dudhi*, etc.

The several species of wheat are subdivided into smaller groups or varieties, these being founded, as a rule, upon a number of morphological differences of the ears and grain. The classification of varieties will be considered in the next section.

The problem of varieties

While the classification of wheats into species is fairly easy and there is quite general agreement on this point, the further classification of these species into sub-groups or varieties presents a problem of considerable complexity. In *T. vulgare* and, to a lesser degree, in *T. durum*, the existing forms are so numerous and so intergrade in all their characters between one extreme and another that the formation of clearly defined groups or classes is almost impossible. Percival [1921] has suggested that the best way of dealing with such extensive material is to make a separate classification of the forms of these species cultivated in each country.

As regards the criteria for the classification of varieties a large number of classifications have been drawn up, varying in the degree of importance assigned to the various characters. These classifications are, almost without exception, based on botanical characters and are frankly artificial. Perhaps the most popular of these is that of Körnicke [1885], being extremely convenient and clearly defined for taxonomic purposes. This is based on the presence or absence of awns, colour of glumes, etc. Under this system, however, as Vavilov [1923] has pointed out, two forms which are alike in all characters save that of glume colour would be placed in two different botanical varieties, whereas forms differing very widely in a whole range of characters but agreeing in the few simple characters used as criteria would be placed in one and the same botanical variety. Hector [1936] in fact says that all such classifications should be regarded merely as ' classificatory guides '. This state of things is hardly surprising when we recall that the varieties within each cultivated wheat species interbreed freely. With the large number of characters available in the wheats and the wide range of variation within each of the characters the number of possible combinations obtainable by hybridization, etc. is almost endless. A formal botanical classification is therefore almost meaningless, and rather than the description of ' types ' themselves, the description of the more important characters with a view to establishing the range of variability available for breeding purposes is desirable. It is necessary therefore to standardize the methods of description and presentation in order that these when published may be of value to all workers on the crop.

Characters to be described

Broadly speaking, the characters to be described are of two kinds : (1) Characters, primarily of a qualitative nature, which are not greatly influenced by external factors. Vavilov [1923] has pointed out that certain of these features characterize whole groups of races and are commonly accompanied by a series of correlative features. Such characters naturally must form the first line of classification in a system which aims at the establishment of genetically akin groups. (2) Quantitative characters which are subject to fluctuation. Some of these are more easily distinguishable and vary less than others, e.g. winter and spring habit, size of grain, etc. and such differences between the forms of wheat can be readily observed by growing the material under the same conditions. Other characters, such as the degree of tillering and the consistency of the grain, fluctuate very greatly and, although of considerable economic importance, they can be used for separating forms only when grown under identical conditions for a number of consecutive seasons.

In order to obtain uniformity in the description of the characters given below it is recommended that as a general rule a sample of 25 normal plants per progeny row be taken for purposes of measurement or description. The observations should be taken over a period of three successive seasons.

A. Plant characters

1. Height of the plant

Height is an important factor and is often related to the resistance or otherwise of the variety to lodging, and to productivity. Height should be measured from the surface of the ground to the tip of the ear, omitting, however,

the awns in the case of awned varieties. Three classes may be distinguished, tall, medium and dwarf. Class limits for these classes should be fixed by the economic botanists in the several wheat-growing tracts and will be understood as applying only to the tract from which the wheats are described. It is not considered desirable to suggest one set of class limits for the whole of India as, obviously, height will be greatly influenced by the locality and the time of sowing.

2. Tillering

Varieties may be classified into those with little tillering and those with much tillering. The average number of tillers at the maximum tillering phase and the average number of ear-bearing tillers should also be given. This character can be used with safety only when the varieties to be compared are grown under identical conditions and over a period of not less than three years.

3. Maturity

The heading date is more convenient to use than the ripening date and the number of days from sowing to complete emergence of the ear should be noted. On the basis of this the wheat varieties may be classified as early, mid-season and late. It is obvious that the maturity is influenced by the time of sowing and will also vary according to the locality. This therefore is another character which must be used with much caution.

B. Ear and grain characters

Ear characters

1. Shape of the ear.—Wheat ears can be classified in respect of shape into four classes : fusiform, oblong, clavate and elliptical (Plate XXI). In common wheats the shapes are determined from a face view of the spikelets, and in club, *durum* and *turgidum* wheats from an edge view of the spikelets.

2. Length of the ear.—Ears may be described as short, mid-long and long. The average length of the ear measured from the ring at the base of the rachis to the tip of the uppermost spikelet (excluding the awn) should be given. The average total number of spikelets should also be stated.

3. Density of the ear.—Ears may be described as lax, mid-dense or dense. Various methods have been suggested for determining the ear density and the most convenient one consists in determining the number of millimetres occupied by 10 internodes of the rachis measured in the middle of the ear. It does not appear to be desirable to fix any rigid limits for the three classes recognized, as there is considerable variation depending upon the locality and season.

4. Position of the ear at maturity.—Erect, inclined and drooping ears may be distinguished.

5. Other characters.—Colour of the anthers—yellow or purple.

Awn characters

1. Presence or absence of awns.—This character has been used by almost all botanists from Linnaeus onwards as the first in order of importance in distinguishing varieties of wheat. Wheats may be entirely beardless, fully bearded or they may possess short awns of varying length ranging from small

tips to the glumes to what may be termed the half-bearded condition. In *T. vulgare* the awns seldom, if ever, exceed 10 cm. in length ; in *T. durum* and *T. turgidum*, however, they may be much longer. Vavilov [1923] has pointed out that hooded forms also occur. They have, however, not been recorded from India.

For purposes of description, wheats may be conveniently divided into five groups : beardless, short-tipped (awnlets not exceeding 5 mm. in length), long-tipped (awnlets 5 to 40 mm. in length), half bearded and full bearded (Plate XXII).

2. *Colour of the awns*.—White, red or black.

This character is easily identified in good seasons but the development of colour varies from year to year and in certain seasons may be entirely absent. The awn colour should be noted before the crop is fully ripe, as in some cases the colour fades at maturity (Plate XXIII).

3. *Arrangement of the awns*.—Awns may be adpressed to the ear, or spreading (Plate XXIV).

4. *Character of the awns*.—Awns may be (*a*) persistent or deciduous, (*b*) coarse and brittle or slender and tough.

Glume characters

1. *Covering of the glumes*.—Glabrous (smooth), sparsely pubescent or densely pubescent (velvety) (Plate XXV).

While presence of pubescence is usually easily recognized, the degree of pubescence varies in different varieties. In some the hairs are much longer and more numerous than in others. *Durum* wheats are generally very densely felted and the hairs are long, whereas the pubescent glumes of the common and dwarf wheats are generally sparsely covered with short hairs.

2. *Colour of the glumes*.—Grades 1 to 9 (Plate XXVI).

The colour of the glumes is usually a shade of yellow or reddish brown. The former are usually described as white, and the latter as red or brown. A few varieties have black glumes or are tinged or striped with black. Glume colours other than these are also found, in some of the lesser-known species.

The depth and tone of the colour varies between different varieties and like awn-colour is influenced by seasonal factors. Unlike awn colour, it should be noted when the ear is ripe.

In some cases the margin is more deeply coloured than the rest of the glume. These should be noted.

3. *Size of the glumes*.—Glume lengths may be described as short, mid-long and long and are illustrated in Plate XXVII, fig. 1. The width of the glumes may be similarly described (Plate XXVII, fig. 2).

4. *Shape of the glume shoulder* (*Plate XXVII, fig. 3*).—The shape of the shoulder—wanting, oblique, rounded, square, elevated or apiculate—is a useful character for determining varieties. Both as regards size and shape of the glumes, the description applies to the middle spikelets of the ear and not to those at the tip or the base which differ widely from the typical spikelets of the ear.

It is unnecessary to point out that in estimating these characters it is desirable to take a number of ears for each variety and to examine a number of glumes in each ear.

5. Size of the glume beak.—(*a*) Width. The width of the beak may be described as narrow, mid-wide and wide (Plate XXVIII, fig. 2). (*b*) Length. As Clark and Bayles [1935] have pointed out, the length of the beak is variable, especially in awned varieties. In most awned wheats the length increases from the base of the ear to its apex, the range of difference varying with the variety. Following Vavilov [1923], beak length may be described as very short (up to 1 mm.), short (1 to 3 mm.), long (3 to 7 mm.) and very long (over 7 mm.). For this purpose the average maximum length measured from the shoulder of the glume upward should be taken. Variations in beak length are illustrated in Plate XXVIII, fig. 1.

6. Shape of the glume beak (Plate XXVIII, fig. 3).—The apex of the beak varies considerably in shape and may be described as obtuse, acute, or acuminate.

7. Tenacity of glumes.—Persistent or deciduous.

The glumes of most varieties are firmly attached to the rachis and are persistent. In some varieties of *T. vulgare*, however, the glumes are easily deciduous, causing the ears to shatter.

Grain characters—

1. Colour of grain.—Grades 1 to 3 (Plate XXIX).

Hayes, Bailey, Arny and Olson [1917] state that 'the visual appearance of wheat which is commonly termed colour is due to the joint effect of two factors : first, the presence or absence of a brownish red or orange-yellow pigment in the bran layer, and second, the physical condition of the endosperm cells. The latter may be corneous or starchy, depending upon the density of the cell contents or the relative amount of space occupied by air cavities or vacuoles'. The grain colour has been used by Körnicke and Werner and others as one of the leading taxonomic characters of wheat.

Howard and Howard [1909] regard the wheat kernel as being either white or red, the tint of colour of both classes varying a good deal. The red wheats vary from dark brownish-red to light red, while the white wheats include yellowish and amber tints. They also state that the particular tone of colour depends partly on the consistency of the grain and, since consistency varies in the same variety, both from year to year in the same locality and also in different localities in the same year, it is not safe to use tone or tint of colour as a distinguishing character. Clark and Bayles [1935] have also grouped kernels of all wheat varieties into two classes—white and red. For Indian wheats it appears desirable to distinguish the amber group from the white and red classes, in view of its commercial importance. All the three colour grades illustrated are found in *vulgare* wheats, whereas in *durum* wheats only grades 2 and 3 are generally found.

2. Length of the grain.—Short, mid-long or long.

As suggested by Clark and Bayles [1935], kernels which are less than 6 mm. in length may be classed as short, those ranging from 6 to 8 mm. as mid-long, and those exceeding 8 mm. as long.

In making measurements only normal grains from the middle spikelets should be used. Ten grains should be taken.

3. Texture of the grain.—The texture of the kernel is an important character as most wheat is marketed in commercial classes based largely on

texture. For purposes of classification, however, the character is a very variable one and to determine it satisfactorily the wheat forms to be compared must be grown under similar conditions for a period of not less than three years.

It is convenient to recognize three classes, viz. soft, semi-hard and hard. Hard wheats are often liable to mottling and the extent of this should be noted.

4. *Shape of the grain.*—The outline of the kernel of *T. vulgare* as viewed from the dorsal surface may be described as ovate, elliptical or oval (Plate XXX, fig. 1). Modifications of these shapes may be indicated by describing the kernels as narrowly or broadly ovate, elliptical or oval, as the case may be.

Both in *T. durum* and in *T. dicoccum* the grains are rather narrow and apering towards both ends. The typical grain of *T. turgidum* is broad and plump with a high dorsal arch or hump behind the embryo. The grain of *T. sphaerococcum* is very characteristic, being shorter and rounder than that of other wheats.

It is important to take only normally developed typical grains from the middle spikelets, and the material to be compared should have been grown under identical conditions.

The tip or brush end of the kernel may be tapering, rounded or truncated.

5. *Width of the crease.*—The crease may be narrow or wide.

6. *Depth of the crease.*—The crease may be shallow or deep, and pitted or non-pitted.

7. *Shape of the cheeks.*—Cheek shapes may be rounded or angular (Plate XXX, fig. 2).

C. *Vegetative characters*

1. Colour of the young shoot

This is usually green but in some cases is purple because of the presence of anthocyanin.

2. Early growth habit

All types occur from prostrate to very erect. It is convenient to distinguish three classes : erect, intermediate or semi-erect, and spreading.

3. Presence or absence of the ligule

Vavilov [1923] has shown that in some wheats the ligule is absent and that it is a useful character for purposes of classification.

4. Colour of the auricles

These may be purple or colourless.

5. Presence or absence of hairs on the auricles

This is an easily distinguishable character.

6. Character of the leaf-sheath

This may be glabrous or pubescent.

7. Pubescence of the leaf-blade

The leaf-blade may be glabrous or pubescent. In the latter class, different grades can be distinguished depending upon the kinds of hairs present and their distribution.

8. Other leaf characters

Leaf-blades of wheat varieties may differ in respect of their colour, size, and in the angle which they make with the culm during the successive periods of growth. The terminal leaf in particular is quite erect in some varieties and drooping at various angles in others : in some it is curled or twisted. These characters, however, are difficult to estimate or are clearly apparent only for a brief period. For this reason they are not proposed to be used. Any very obvious differences, such as very broad or very narrow leaves, should, however, be noted.

9. Glaucousness of the plant

Plants may be glaucous or non-glaucous.

10. Colour of the stem

The stem colour may be green or purple. This should be determined about 10 days before ripening.

11. Thickness of the straw

Varieties may be grouped into : (*a*) those with thick straw, and (*b*) those with thin straw.

12. Solidity of the straw

The straw in the upper part of the culm below the ear may be solid or hollow.

D. Other characters

1. Yield

While it is the most important character from the point of view of the grower, yield does not readily lend itself for use in classification. The results of properly replicated and randomised trials carried out over a series of years, however, form useful measures of the comparative productivity and should be noted.

2. Quality

Quality in wheat is difficult to define. A note on this subject appears as Appendix II. The bushel weight, 1000-kernel weight and protein content should be given as explained therein. As already mentioned, grain colour and texture should also be described.

3. Disease-resistance

Resistance and susceptibility to specific diseases should be determined under conditions favourable for the maximum development of the disease and such that all the varieties are equally exposed to the disease. When physiologic races of the disease-causing organism exist, this fact should be taken into account in planning the tests. The results of such tests where known should be noted in the varietal descriptions.

4. Resistance to cold, heat, drought, lodging, etc.

The resistance or susceptibility of varieties to various adverse conditions should be mentioned whenever this information is available.

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APPENDIX I

(*a*) *Specimen schedule*

1. Experiment Station
2. Nature of soil
3. Average rainfall (average of 5 years) — (*a*) For the whole year; (*b*) For the wheat season (months to be stated)
4. Temperature range (average of 5 years) — (*a*) For the whole year; (*b*) For the wheat season
5. Humidity range (average of 5 years) — (*a*) For the whole year; (*b*) For the wheat season
6. Nature and amount of manure applied
7. Date of sowing
8. Seed rate
9. Average spacing
10. Number of irrigations, with intervals
11. Layout

(b) *Ear and grain characters*

STRAIN		EAR CHARACTERS					AWN CHARACTERS				GLUME CHARACTERS							GRAIN CHARACTERS										OTHER CHARACTERS	REMARKS
Old name or number	New name or number	Shape of the ear	Length of the ear	Density of the ear	Number of spikelets	Position of the ear at maturity	Presence or absence of awns and degree of awning	Awn colour	Arrangement of the awns	Character of the awns	Glume hairiness	Glume colour	Glume size	Glume shoulder shape	Beak size	Beak shape	Tenacity of the glumes	Grain colour	Grain length	Grain texture	Grain shape	Crease width	Crease depth	Cheek shape	Bushel weight	1000-kernel weight	Protein content	Anther colour	

(c) *Vegetative and other characters*

STRAIN		LEAF AND STEM CHARACTERS											OTHER CHARACTERS							REMARKS
Old name or number	New name or number	Colour of the young shoot	Early growth habit	Presence or absence of the ligule	Auricle colour	Auricle hairiness	Leaf-sheath hairiness	Leaf-blade hairiness	Other leaf characters	Stem colour	Straw thickness	Solidity of the straw	Plant glaucousness	Plant height in cm.	Number of tillers per plant	Maturity (number of days from sowing to heading)	Yield per plant in gm.	Disease-resistance	Resistance to adverse conditions	

APPENDIX II

Quality in wheat

Quality in crops, and for the matter of that in wheat, is a highly ambiguous term. The layman often thinks that it is associated with nutritive value. But this is not really the case, as in practice quality is generally tantamount to commercial desirability and therefore is closely related to the uses to which the products of a particular crop are generally put. Wheat, for example, is mostly consumed in the form of loaves (leavened bread) or, as in India and most other Asiatic countries, in the form of *chapatis* (unleavened pancakes), and quality in wheat has therefore to be mainly judged from these two standpoints. Such a judgment, however, is not easy to make, as in either case quality is a composite, complex character, being the resultant of a number of physiological characteristics, which are highly subject to the influence of environment and are, therefore, very variable. To appraise these characteristics correctly, it is necessary to collect data for a number of years, at least three, by comparing the varietal material under identical conditions of growth and culture. There is no doubt that the final and most reliable proof of the milling and baking qualities of wheats can only be obtained by properly planned, actual milling and baking (including *chapati*-making) tests, but as such work requires the assistance of modern milling and baking laboratories, which, with the solitary exception of the one recently started at Lyallpur, do not exist in India at present, it is not possible to subject to such tests locally the numerous types and cultures which the Indian plant breeders may have to handle, even if sufficient quantities of the seed of the latter were available. Therefore, the Indian breeding material under study can only be tested and characterized with reference to the most important characteristics which go to make up baking quality and which can be assessed with simple appliances available in an ordinary research institute and without the aid of an elaborate cereal technological laboratory.

The loaf-making quality of a wheat variety depends in the main on the rate of gas production and on gas retention when the dough made from its flour is subjected to yeast fermentation and later to baking in the oven. The gassing power in turn depends on diastatic activity, but, as the influence of variety on diastatic activity is only secondary and, as hardly any breeder will have the necessary facilities and the necessary time for making such determinations, it would simply be a counsel of perfection to lay down that this should be attempted. The appraisement of this characteristic may therefore ordinarily be left out. The power of gas retention, on the other hand, is mainly a varietal trait and depends on the quantity and quality of gluten, which in turn are generally a direct function of the protein of a wheat. It is important therefore that a breeder should obtain information on the protein content and quantity and quality of gluten of his wheat breeding material so as to be able to select the most desirable sorts and to discard types that do not come up to the mark in these respects. In order to base the work of selection and rejection on still more secure foundations, he must also collect data on some other points which, while easily determinable, may with advantage supplement the information collected by him with regard to protein and gluten. It is therefore felt that determinations in respect of the following characteristics would supply as sound a basis for the selecting and discarding of types as is possible with the facilities ordinarily available to a wheat breeder.

Texture.—Wheats may be hard, semi-hard or soft, irrespective of whether they are white or red. Generally soft wheats have a low and hard ones a high baking quality. It is easy to distinguish between soft and hard wheats from their appearance as soft ones when cut across present a mealy or starchy appearance, whereas

hard ones when so treated look translucent or glassy. Hard wheats are often liable to mottling, i.e. to the presence of soft patches in their endosperm on a hard background, which defect is a serious one. Although there is hardly any variety which under adverse conditions would escape mottling, yet varieties do differ among themselves with regard to their liability to mottling, and freedom from mottling is a point of quality of irresistible appeal to all concerned in the handling of wheat. Therefore, in describing the grain texture of wheats, not only should it be stated that they are hard or soft, but also the extent of mottling in them should be noted, taking for comparison wheat Punjab C 591 as the standard, which is much less liable to mottling than most other Indian wheats.

Bushel and 1000-kernel weights.—As the milling quality of a wheat depends on the yield of flour which it gives and as the yield of flour is correlated with the bushel and 1000-kernel weights, these should be given whenever possible. Bushel weights, which even with small samples can easily be determined by the use of a chondrometer, should be taken on a cleaned wheat basis and under three classes, viz. low, less than 60 lb.; medium, 60 to 62 lb.; and high, above 62 lb., per bushel. Corresponding limits for the 1000-kernel weight in the case of bread wheats, may be taken to be somewhat as follows :—

(1) Low, less than 30 gm.
(2) Medium, 30 to 35 gm.
(3) High, over 35 gm.

Protein content.—This is a better indicator of strength in bread wheats than any other one chemical measure and, when combined with the determination of the quality of gluten which the protein of a wheat yields, gives a very good indication of the baking quality of a wheat. A high protein content is not only a general indicator of high baking quality, but usually also an indicator of good water-absorbing capacity and of high food value, and for this reason may also be of value in assessing the *chapati*-making properties of a wheat. Three following protein classes may tentatively be adopted for classifying Indian wheat :—

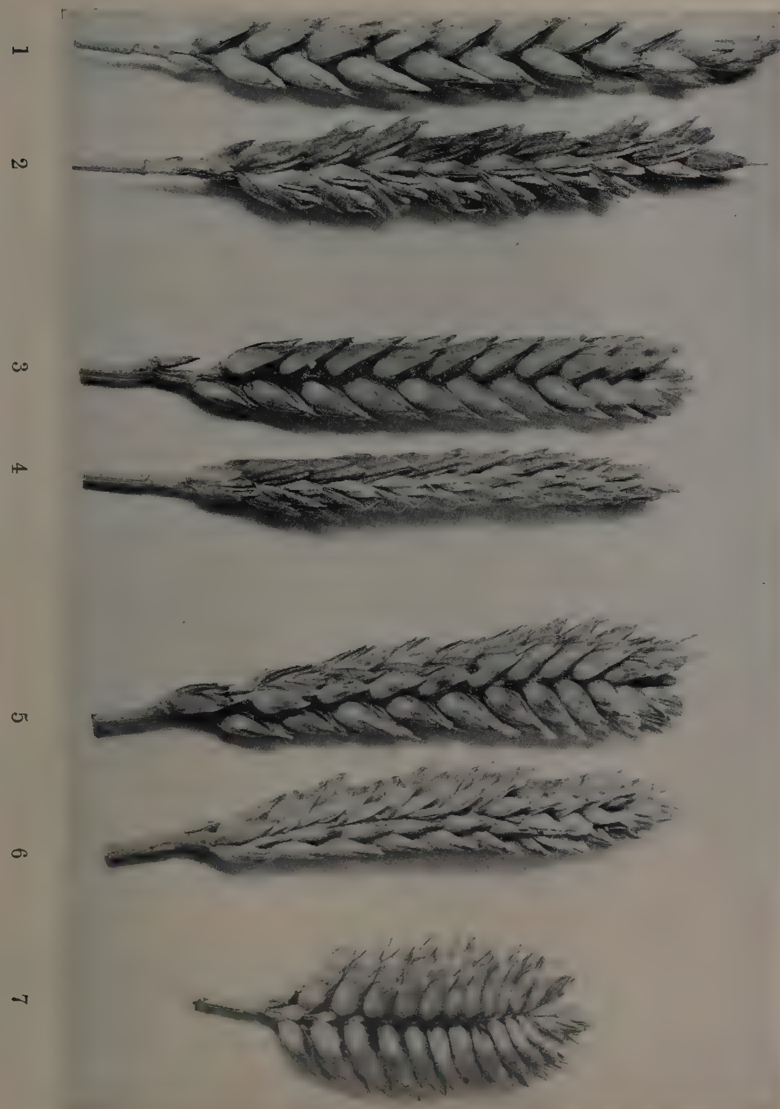
(1) Low protein content, less than 9 per cent
(2) Medium protein content, 9 to 12 per cent
(3) High protein content, above 12 per cent

Gluten.—Whenever possible, the weight of wet and dried gluten yielded by 10 gm. of fine wheat-meal should be given and also the ratio between wet and dry gluten, which supplies a rough comparative measure of the water-absorbing capacity of the flour. The quality of the gluten should also be stated. It may be short, i.e. incapable of much stretching and may therefore break off in a sharp manner when stretched. Such gluten is of poor quality. On the other hand, it may be smooth and possess good elasticity, extensibility and spring—all signs of good quality.

Wheat-meal-fermentation-time tests.—A very useful micro-test of quality is furnished by what is known as the wheat-meal-fermentation-time test which consists in immersing a dough ball, made of 10 gm. of wheat-meal and 5·5 c.c. of 10 per cent yeast suspension in 80 c.c. of distilled water (contained in a low-form beaker) maintained at 80°F. The time-interval in minutes between the immersion of the dough ball and when it starts to disintegrate serves as a measure of gluten quality. The longer this time-interval, generally better the quality of gluten or the baking power of wheat under study.

However, in making this test, as the time-interval also depends on the quality and activity of the yeast employed, it would appear that, instead of laying down any limits for the various classes, it would be advisable to take Pusa 4 or Punjab 8B as the standard of highest excellence and present the results by stating how far the wheat under consideration falls short of either of these standards.

Baking tests.—As already stated, it would hardly be possible for a breeder to have the quality of his wheat varietal material tested by extensive actual baking tests, but wherever this may be found possible, Pusa 4 or Pusa 111, on account of their high baking quality, should be employed as standards for judging the loaf-making quality. Similarly, for testing the *chapati*-making properties, Punjab C591, on account of its excellence in this respect, should be taken as the yardstick.



Shape of ears : (1,2) fusiform ; (3,4) oblong ; (5,6) clavate ; (7) elliptical

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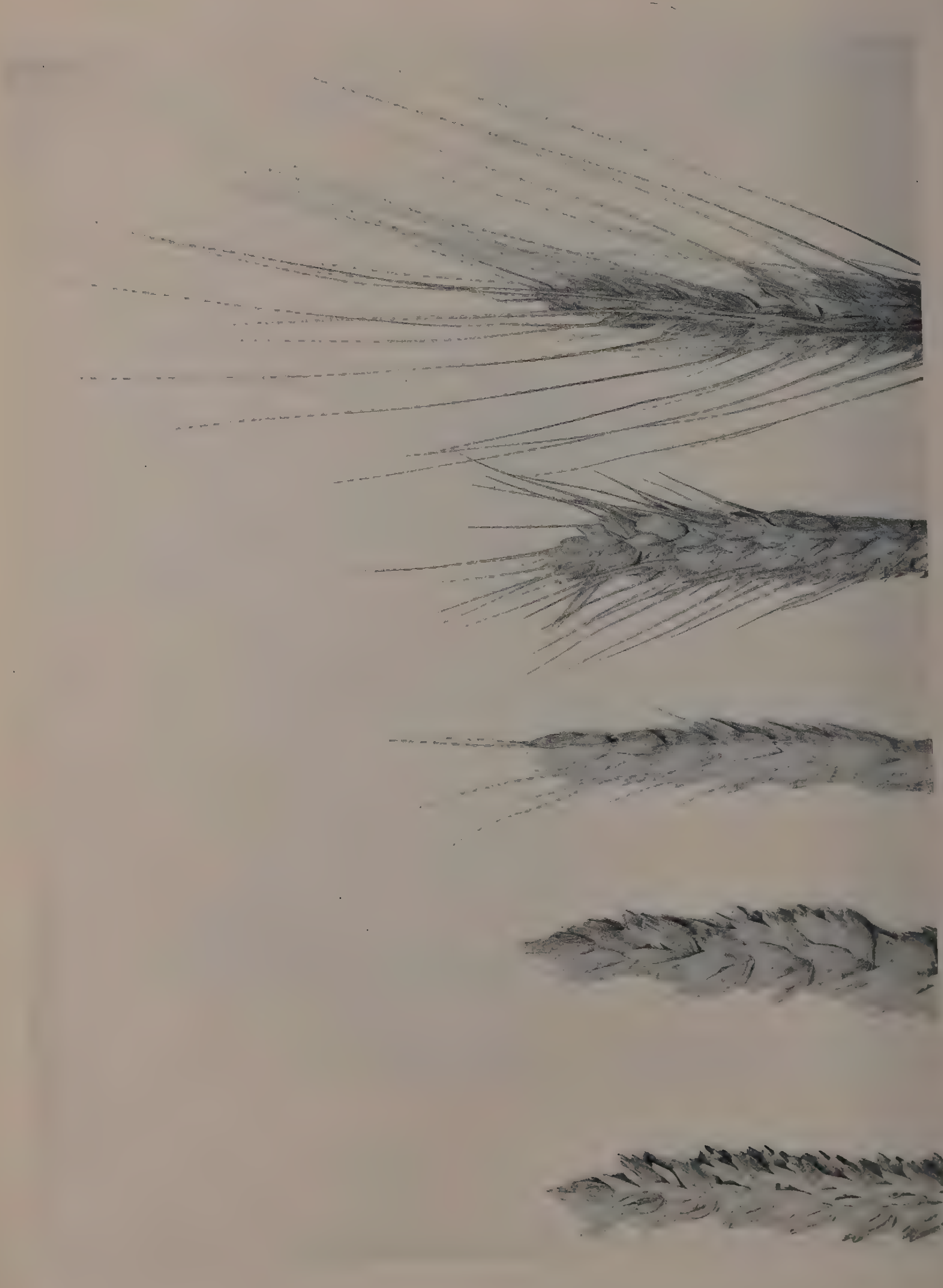


5

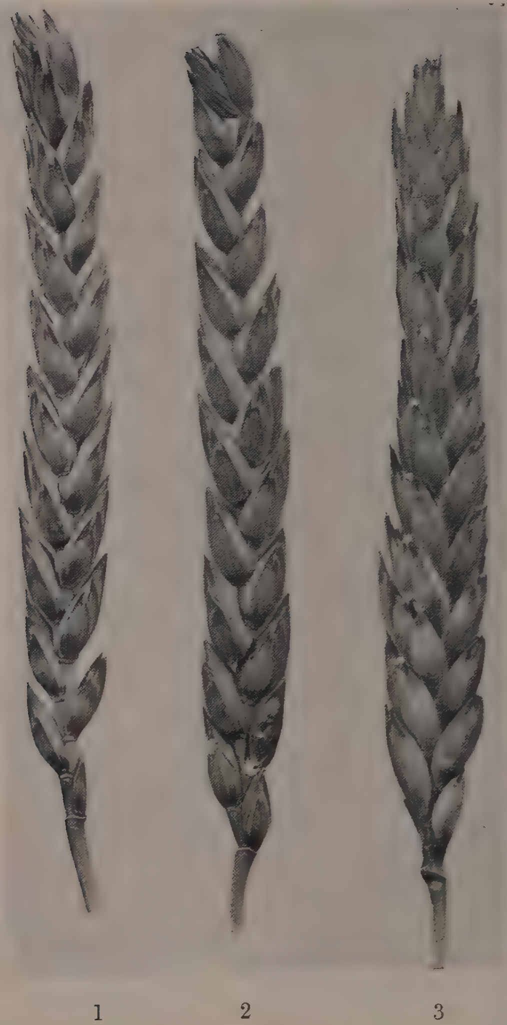
4

3

Awn colour : (I) white, (2) red, (3) black

1 2

Awn arrangement : (1) adpressed, (2) spreading



Degree of pubescence : (1) glabrous, (2) sparsely pubescent, (3) densely pubescent

Glume colour : Grades 1 to 9

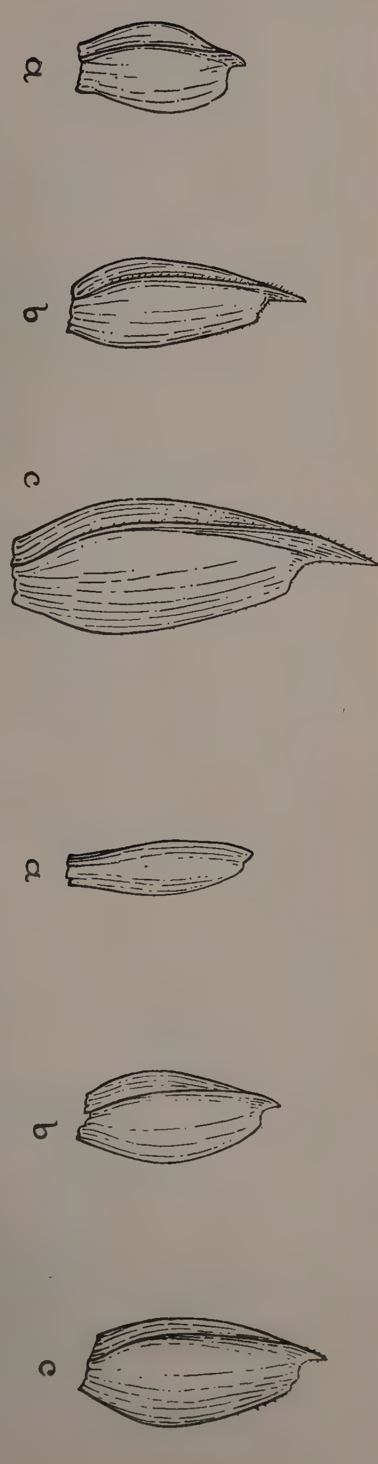


FIG. 1. Glume length: (*a*) short, (*b*) mid-long, (*c*) long

FIG. 2. Glume width: (*a*) narrow, (*b*) mid-wide, (*c*) wide

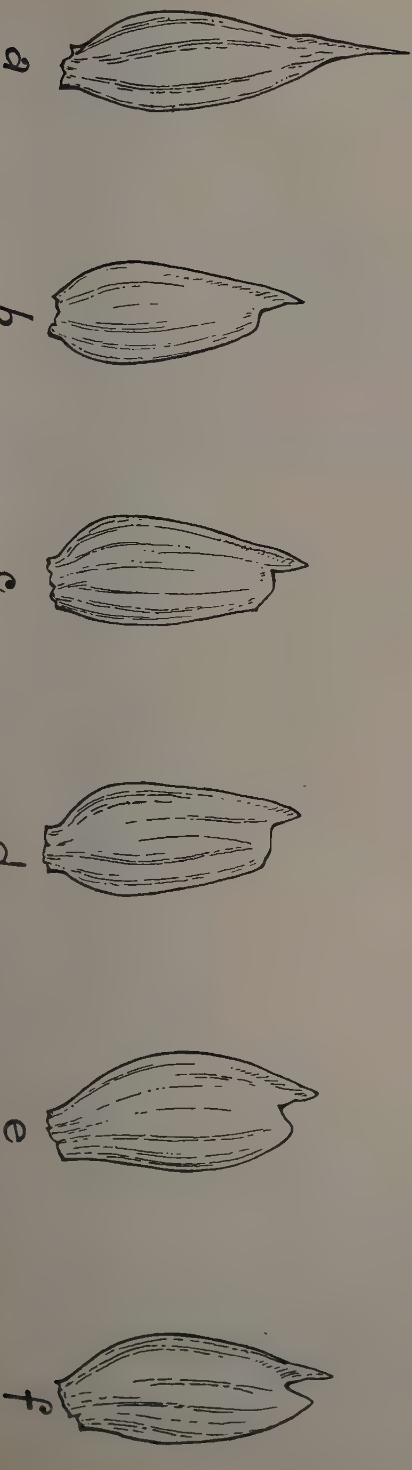


FIG. 3. Glume shoulder shape: (*a*) wanting, (*b*) oblique, (*c*) rounded, (*d*) square, (*e*) elevated, (*f*) apiculate

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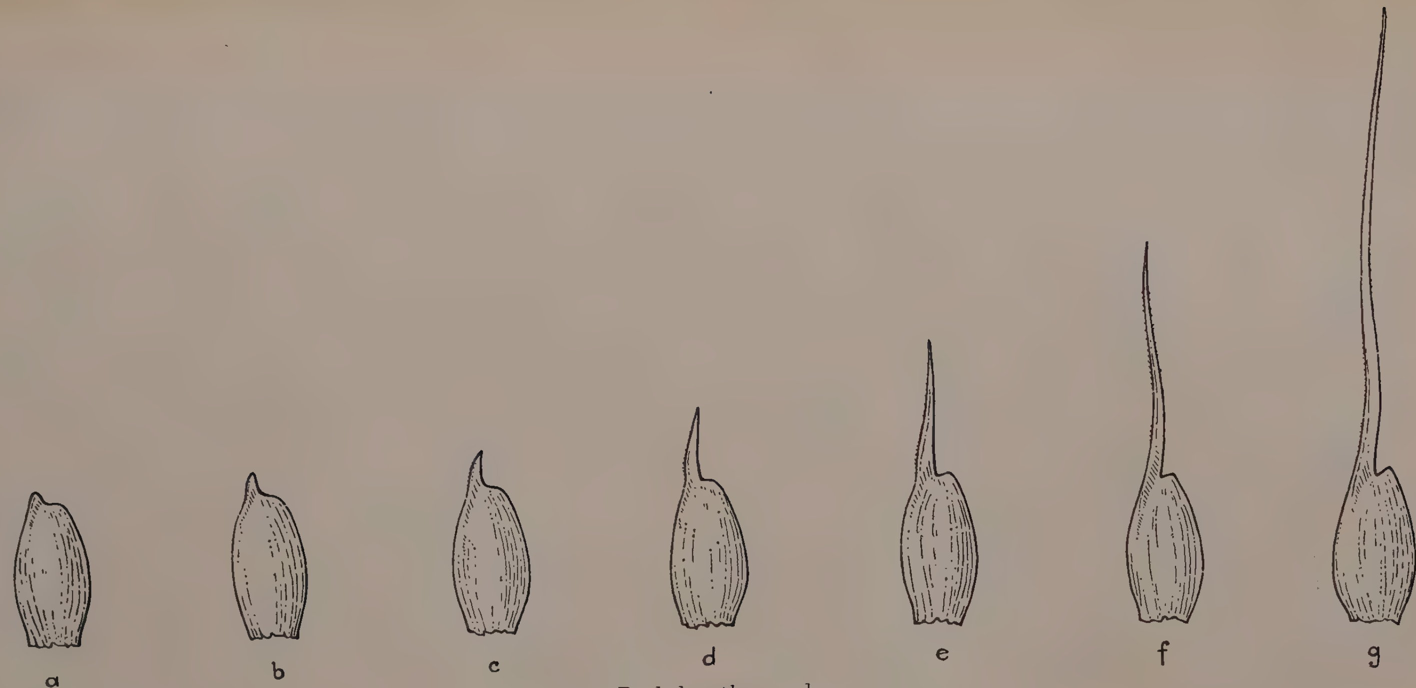

FIG. 1. Beak length : grades $a-g$

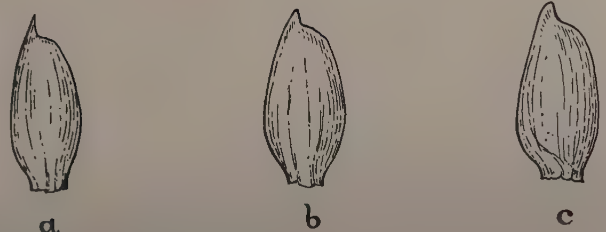

FIG. 2. Beak width: (*a*) narrow, (*b*) mid-wide, (*c*) wide

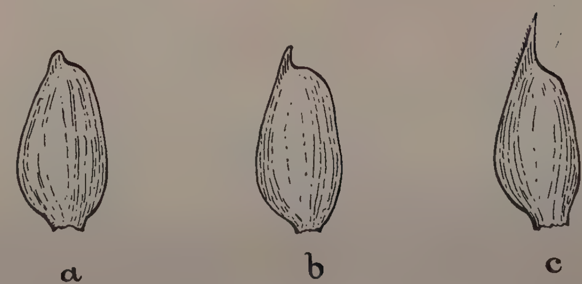

FIG. 3. Beak shape: (*a*) obtuse, (*b*) acute, (*c*) acuminate

1

2

3

Grain colour : (1) white, (2) amber, (3) red

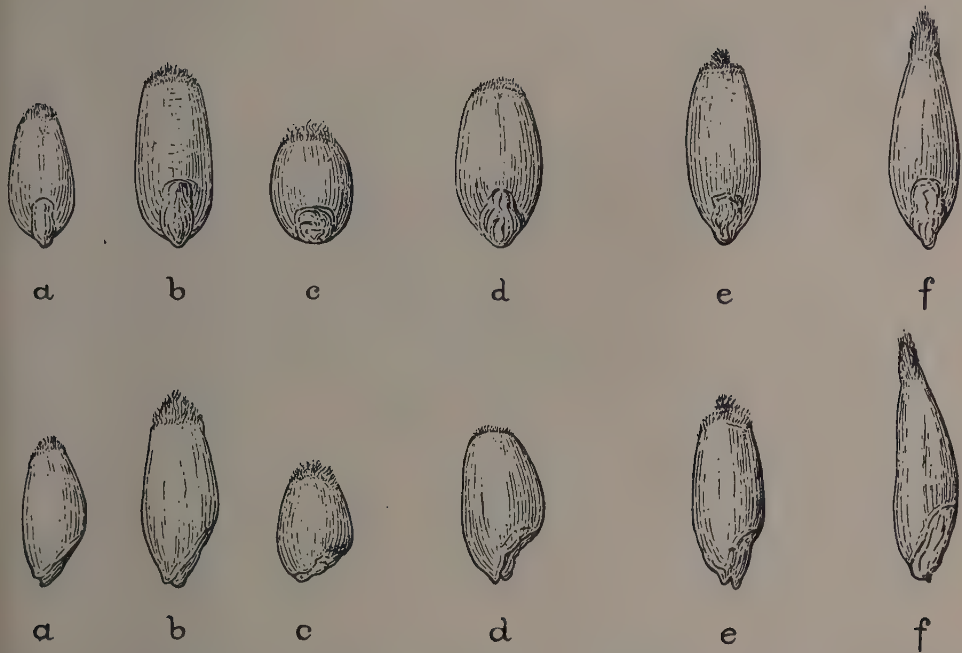

FIG. 1. Grain shape (1st row) : *a,b,c,=T. vulgare* : ovate, elliptical and oval ; *d=T. turgidum ; e=T. durum ; f=T. dicoccum*
(2nd row) : side view of the above

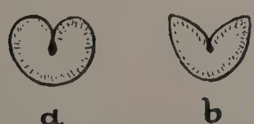

FIG. 2. Cheek shape : rounded and angular

SURFACE RUN-OFF AND SOIL EROSION FROM ARABLE LANDS IN THE BOMBAY-DECCAN

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(With Plates XXXI and XXXII and eight text-figures)

Introduction

It is universally recognized that, in the famine areas of the Bombay-Deccan, the most important single factor contributing to crop failures is the inadequacy of soil-moisture which is entirely dependent upon the monsoon rains, often precarious and uncertain in this tract. In an examination of the problem of these crop failures under the Bombay Dry Farming Research Scheme, investigation into the ultimate disposal of rain water naturally forms an important plank in the research programme of the Scheme. It is obvious that a considerable part of the rain water is lost by surface run-off but no definite information regarding the actual quantity of rain water lost in this manner, nor the circumstances under which such losses occur, is available. Rain water, while running over cultivated, fallow or grazing lands, removes part of the surface soil, causing what is known as sheet erosion which is sometimes difficult to recognize. Where such water gains bulk and momentum, e.g. at lower levels, it causes gully erosion which can generally be easily recognized on account of its conspicuous eroding effect. Investigations into the run-off of rain water thus necessarily include the determination of the extent of soil erosion of both the types mentioned above.

Evidence placed before the Royal Commission on Agriculture in India [1926] showed that the action of monsoon rains on the sloping hillsides of upland tracts in peninsular India, more especially in the southern districts of the Bombay province, produces soil erosion similar to that produced by fluvial action of rivers in Northern India. The Royal Commission, therefore, recommended that 'the exact extent of soil erosion in the Bombay Presidency should be investigated.'

In the programme of work under the Bombay Dry Farming Research Scheme at Sholapur, elaborate experiments have been included to determine the loss of rain water by run-off and also the extent of erosion by rainfall on

arable lands. Prior to these experiments at Sholapur, experiments of a preliminary nature were carried out under the Soil Physicist to the Government of Bombay at a small Dry Farming Station at Manjri near Poona from 1929 to 1933. The plot, however, on which these early experiments were carried out, had a slope that was much greater than the average slope of the majority of agricultural lands in the Bombay-Deccan. The experiments which are herein described were laid down on a piece of land with a natural slope which could be considered to be typical of the majority of agricultural lands in the Bombay-Deccan. No similar experiments to determine the extent of soil erosion from arable lands have been done before in India and the results presented here are the first of their kind, not only in the Bombay-Deccan, but also in the whole of India.

Sir Archibald Geikie has mentioned in his *Text-book of geology* the huge figure of 356·3 million tons of solid matter as being carried off the land by the Ganges during a single year. Sahasrabuddhe [1929] has given a figure of little less than 100 tons of solid matter estimated to be carried away by the Mula river near Poona on a day during the monsoon. With the exception of such limited references of a general nature, no data of any precise character are available with regard to the quantitative aspect of erosion of arable lands in India.

Some experiments on this subject have been reported by Gorrie [1938] from the Punjab, but these were carried out on forest soils and the plots chosen for experimental work were very small.

A very large number of experiments on rainfall run-off and soil erosion have been carried out at a large number of experimental stations in the U. S. A. and, of late, the subject of soil erosion has received considerable attention all over the world.

II. Review of previous literature

As an outcome of this work, a mass of data has now been collected and published. In this section, however, only such literature which bears directly on the experiments described in this paper is briefly reviewed. Two comprehensive publications on soil erosion and its control in different countries have been published by Eden [1933] and Jacks and Whyte [1938]. Recently, Gorrie [1939] has compiled a bibliography of Indian work dealing with the subject of soil erosion.

There is a consensus of opinion that all rainfalls do not produce run-off and erosion. Dickson [1929] noticed very heavy erosions with an average annual rainfall of only 21·68 inches. Lowdermilk [1931] found a correlation between run-off and intensity of rainfall. On the other hand, Conner, Dickson and Scoates [1930] failed to establish any direct relation between erosion and intensity of rainfall. They found, however, that run-off was influenced by the moisture content of the soil at the time of rainfall. Christiansen-Weniger [1934] is of the opinion that 'average precipitation is of little importance, the chief factors being maximal precipitation and the distribution of rainfall in the different seasons.' It seems, therefore, that the total rainfall of a tract is no criterion for judging the possibility of the occurrence and extent of erosion. It is the intensity of rainfall that is most responsible for causing run-off and erosion.

The amount of rainfall lost as run-off has been measured by a few workers. Mosier and Gustafson [1918] noticed a marked seasonal variation in percentage run-off. Over a period of three years, the run-off varied from 31 to 50 per cent of the annual rainfall. Gorrie [1938] recorded a run-off varying from 5 per cent, in the case of plots covered with grass and shrub, to 25 per cent from a bare soil. As regards the amount of silt lost per acre as a result of rainfall run-off, the results vary considerably. In Russia [Jacks and Whyte, 1938], the average soil losses varied from 20 tons per hectare per annum on gentle and moderate slopes to 50 tons on steep slopes. In Ceylon, Holland and Joachim [1933] found that, under current estate practices, the loss by erosion varied from 56 to 101 tons per acre during a period of six years. Gorrie [1938], in India, records nearly 8 tons per acre as the amount of soil lost from a bare plot during a single monsoon.

The effect of some sort of cover on soil has been recorded by several workers. Duley and Miller [1923] found that plots under annual crops suffered more than plots under sod. They also noticed that a wide-sown crop, like maize, allowed more run-off and erosion than a close-spaced one. Holland and Joachim [1923] found that soil erosion was greater in control plots than in plots having vegetation. In Africa very similar results were obtained by Thompson [1935] and Staples [1936]. Thompson found that 'annual hay crops were less detrimental. Among perennial planted grasses, Rhodes grass was not effective in preventing erosion and run-off.' Staples obtained the least percentage run-off with perennial grass and deciduous thickets, followed by Bulrush millet. Russian investigators, as quoted by Jacks and Whyte [1938], have come to a similar conclusion as regards the importance of grass in preventing run-off and erosion.

As regards the effect of cultivation, the data of Lowdermilk [1931], Holland [1930] and Duley and Miller [1923] show that cultivation increases the rate of erosion. Duley and Miller's results show that, while cultivation increased erosion, it reduced run-off. Deeper cultivation, however, was found to cause less erosion than shallow cultivation. The results obtained by Miller and Krusekopf [1932] fail to substantiate the common belief that deep ploughing is markedly better than shallow ploughing in reducing erosion losses. The results of Staples [1936], however, show that flat cultivation on a bare plot caused less run-off and erosion as compared with a bare uncultivated plot. Eden [1933] cites other workers who consider deep tillage to be effective in checking erosion, though, in conclusion, he observes that the effect of cultivation must be regarded as an open question.

Duley and Ackerman [1934] recorded a larger percentage run-off from short plots than from long ones. Their results on soil erosion were less consistent but they appear to indicate that, when the rainfall is light, short plots may undergo greater erosion, but that the reverse is true when the rainfall is heavy.

As regards the amount of nutrients removed in the process of soil erosion, Duley and Miller [1923] observe that the losses are in some cases greater than the annual crop requirements. The losses in general follow the trend of the actual losses of soil. Most of the nitrogen is removed from the soil as organic nitrogen, the loss of nitrates being very low. This view was later confirmed by Duley [1926] who found very little nitrates in run-off water. He found

that calcium formed the largest proportion of the total nutrients removed in the run-off water.

Miller and Krusekopf [1932] support the findings of Duley and Miller. Their mechanical analysis of the eroded material showed that the uncropped plots lost more sandy material than the others.

Just as soil type influences erosion, erosion changes the soil type. Bennett [1931] gives examples of new soil types having been formed by erosion. In many cases the present surface soil is the original 'B' horizon. This leads to the formation of what are known as truncated profiles. Elsewhere, e.g. in Russia and Africa [Jacks and Whyte, 1938] and in England [Robinson, 1936], similar cases have been recorded.

III. Factors affecting run-off of rain water and soil erosion

The environmental factors that influence the extent of run-off of rain water and of consequent soil erosion are :—

(1) Topography, (2) soil types and their geological origin, (3) vegetation cover and (4) the climatic factors, of which the temperature and the extent and distribution of rainfall are the most important.

The area under the Dry Farming Research Station, Sholapur, is very representative of an extensive tract of the Bombay-Deccan, which is liable to periodic famines and scarcity. This tract includes the three entire districts of Ahmednagar, Sholapur and Bijapur, and also the eastern portions of Nasik, Poona, Satara, Belgaum and Dharwar districts. It forms the area lying between E. longitude 74° and 76° and the parallels of latitude 16° and 21° N. L. and is about 26,000 square miles in extent. The Western Ghats or the Sahyadri range of mountains forms the western boundary of this tract. In fact, the Sahyadri range itself is a comparatively less eroded ridge of hard Deccan trap of volcanic origin. Numerous spurs from the Sahyadri range extend to the east and protrude at right angles to the main range into the tract forming the Bombay-Deccan. The general slope of this region is towards the east. The whole tract, therefore, consists of a plateau or a tableland with gentle undulations intersected by spurs from the Sahyadri range at right angles to the main range, thus forming a series of ridges and valleys across the plateau. The elevation of the Deccan Plateau ranges from about 2,000 ft. in the west to about 1,400 ft. at the eastern boundary of the Bombay province. The geological formation of the whole area forming the Bombay-Deccan from the river Godavari in the north to the river Krishna in the south is the well-known Deccan trap or basalt. To the south of the Krishna river in the Bijapur district, other formations of the transition series and of still older periods are met with. The whole tract which is gently undulating with alternate ridges and narrow valleys, consists of agricultural lands which have undergone varying degrees of erosion, leaving only a thin cover of soil in many places. Along the banks of the rivers, more extensive, level and deep lands are to be found. These topographical features which are the result of geological agencies, influence very greatly the run-off of rain water and the extent of soil erosion in different portions of the tract. A detailed contour map of any portion of the tract shows very distinctly the undulating character of the area. The map of Bijapur taluka (Fig. 1), which is given as an

illustration, shows that the area is traversed by a large number of *nallas* and their tributaries. All these *nallas* finally coalesce into larger streams such as the Don or the Krishna rivers and serve as surface drains for the storm-water received during heavy and intensive showers in the monsoon months. Accordingly, every year these rivers and streams carry away millions of tons of suspended soil or silt from the agricultural lands of the tract which mainly consists of the finer and more fertile fractions of soil. The area is characterized by the absence of any large tree growth except in the region of heavy rains just adjacent to the Western Ghats. Even annual vegetation is generally stunted and of very poor growth. The open, bare and uncovered nature of the tract facilitates losses of rain water and contributes to soil erosion on an extensive and widespread scale.

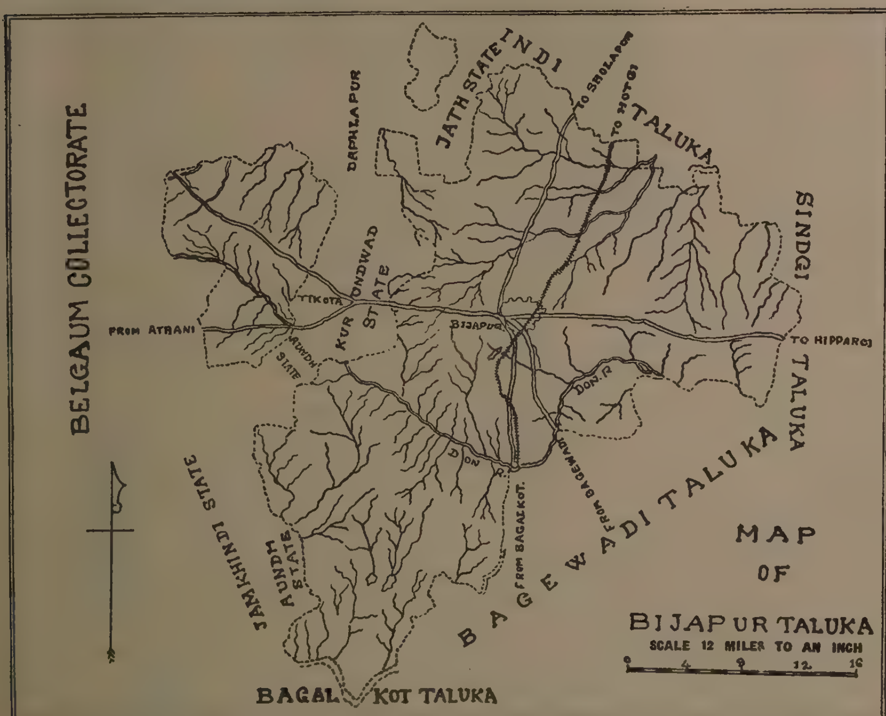

FIG. 1. Map of Bijapur taluka showing natural surface drains

IV. Climatic factors influencing run-off and soil erosion in the Bombay-Deccan

(*A*) *Temperatures*

As the atmospheric temperatures of the tract at different periods of the year have an indirect influence on the extent of run-off and erosion, they are discussed here very briefly. In this extensive tract, the prevalent tempera-

tures throughout the year show considerable variance from north to south as well as from west to east. The extent of elevation above sea-level also has considerable influence on prevailing temperatures. If the records of temperatures at the four important district towns are examined (Table I), they clearly indicate the great range through which the seasonal temperatures of the tract fluctuate.

TABLE I*

Record of temperatures at important towns

	Nasik north-western area	Ahmednagar north-eastern area	Sholapur south-eastern area	Bijapur south eastern area
Highest monthly mean maximum (°F.)	100	103	106	104
Lowest monthly mean minimum (°F.)	48	51	56	55
Absolute maximum (°F.) .	107	110	110	108
Absolute minimum (°F.) .	42	44	48	46

* Figures given in Tables I and II are from the Statistical Atlas of the Bombay Presidency [1925].

The highest monthly mean maximum and the lowest monthly mean minimum temperatures show a difference of nearly 50°F. at all stations, while the absolute maximum and minimum show a difference of more than 50°F. during the year. The maximum temperature is reached either in April or May, while the minimum is experienced either in December or January. The air is very dry for six months of the year from November to April. During this period, the soils become extremely dry and loose and are easily blown away by the wind and carried off in suspension by water if a heavy shower of rain is received. More detailed data regarding temperatures and humidity from month to month at Sholapur are given later while discussing experimental work at this centre. The figures given above for the four recording centres illustrate how the maximum temperatures increase from north to south and also from west to east. The minimum temperature is lowest in the northern tract, as represented by Nasik, and gradually rises towards the south, i.e. Sholapur and Bijapur.

(*B*) *Rainfall*

The average monthly rainfall statistics for the same four centres show how the total rainfall, and more particularly its distribution from month to month, vary from west to east.

TABLE II

Average monthly rainfall in inches

Month	Nasik north-western area	Ahmednagar north-eastern area	Sholapur south eastern area	Bijapur south eastern area
January	0·10	0·17	0·15	0·09
February	0·04	0·13	0·07	0·06
March	0·03	0·10	0·20	0·22
April	0·18	0·23	0·46	0·80
May	0·92	0·92	1·05	0·31
June	5·57	4·57	4·67	3·37
July	8·67	3·61	4·20	2·51
August	5·09	2·77	4·54	2·88
September	5·93	6·84	7·71	6·33
October	2·81	2·78	3·02	3·88
November	0·46	0·83	1·05	1·52
December	0·18	0·55	0·46	0·31
Annual total	29·98	23·50	27·55	23·28
Average number of rainy days*	48·6	36·1	41·3	36·1

* According to the practice adopted by the Meteorological Department, only such days as receive 10 cents or more of rainfall during the 24 hours are counted as 'rainy days'. The same procedure is followed in calculating the data dealt with throughout in this article.

The rainfall at Nasik is typical of the south-west monsoon, which is restricted to a period of five months from June to October. This rainfall is generally evenly distributed during the four months of June to September and is usually received spread over a large number of rainy days. The maximum rainfall is received in July. Under such conditions, the effects of surface run-off and soil erosion are limited. The rainfall at each of the other three stations is similar in character and represents the type of monsoon generally experienced in the eastern parts of the Bombay-Deccan. The rainfall received during the first three months (i.e. June-August) amounts to about 50–55 per cent of the total precipitation, while the remaining rainfall occurs from September onwards. The number of rainy days is limited, especially during the latter part of the season. The rainfall in this tract largely consists of

intermittent heavy showers of great intensity. It should be remembered that the figures given in Table II are averages. The actual figures obtained in any one year may deviate very considerably from them. Such variation can be seen from the rainfall figures for five years at Sholapur which are given later.

Two other important factors which influence the climate of the tract are the average wind velocity and the atmospheric humidity. The nature of both these factors in the eastern tract differs considerably from their nature in the western tract of the Bombay-Deccan. These factors tend to make the climate in the eastern tract dry and desiccating even during the monsoon months, and, in this area, facilitate the quick drying of the surface soil after it has become loose and pulverized by such agricultural operations as harrowing and weeding. Therefore, the heavy downpours of rain, common in September and October, cause serious losses of such dry, loose and pulverized soil by erosion.

V. Experiments on rainfall run-off and soil erosion at the Sholapur Dry Farming Research Station

To begin with, experiments were laid down with a view to finding out as accurately as possible the amount of rain water lost by surface run-off and to enable an approximate estimate to be made of the total amount of soil carried off annually by erosion on a representative soil of the tract under the different methods of cultivation and cropping common in the south-eastern part of the Bombay province. The slope of the land chosen for this experimental work was as far as possible selected so as to be representative of the average slope to be found on the majority of the cultivated fields in the tract. The experiments were laid out on the same plan as was followed by Duley and Miller [1923] in their classical experiments at Missouri in the U. S. A., but due to differences in local environment, the plot dimensions chosen and the slope used were somewhat different from those adopted by these workers.

VI. Soil type and its physical and chemical characters

The soil of the experimental plots can be described as medium deep soil the depth varying from 9 in. to 18 in. This soil is derived from decomposition of the Deccan trap and is of a residual type, a portion of the 'A' horizon having been lost by previous erosion. Such decomposed trap is found immediately below the comparatively thin layer of surface soil. The colour of the soil is dark brown and it shows a compact constitution with the texture of heavy clay. The mechanical composition of the soil as determined by the International Soda Method is given below.

These data indicate that the soil contains a very high percentage of clay and can therefore be classified as belonging to the heavy clay type. Study of some of the physico-chemical constants indicates that this soil has a high moisture equivalent of 43·6, a high wilting coefficient of 20·10, sticky point of 57·7, with a shrinkage value of 62·7. The total exchangeable bases have been found to be 38·4 m.e. of which exchangeable lime is 30·0 m.e. It has a wide C : N ratio of 17 : 1 and the *p*H value of 8·14. The chemical composition of the soil, determined from the results of analysis by digestion with hydrochloric acid, is given in Table IV.

TABLE III

Mechanical analysis of soil of experimental plots

Expressed on per cent dry matter

	Surface layer 0—9 in.	Sub-surface layer 9—18 in.
Stones per cent on original soil	5·28	6·87
Loss by solution	1·64	2·67
Coarse sand	0·71	2·34
Fine sand	11·67	9·18
Silt	26·86	26·33
Clay	58·49	58·60
Difference	0·63	0·98

TABLE IV

Chemical analysis of soil of experimental plots

Expressed on per cent dry matter

	Surface layer 0—9 in.	Sub-surface layer 9—18 in.
Loss on ignition	7·73	8·58
Sand and silica	65·65	64·42
Iron oxide (Fe_2O_3)	10·99	10·48
Aluminium and titanium oxides ($Al_2O_3 + Ti_2O_3$)	11·48	11·29
Lime (CaO)	1·48	2·32
Magnesia (MgO)	0·35	0·79
Potash (K_2O)	0·44	0·48
Phosphoric acid (P_2O_5)	0·06	0·05
Nitrogen (N)	0·039	0·040

These figures show that the loss on ignition is high and is largely due to the combined moisture held by the colloids resulting from the high percentage of clay. The amount of sand and silica is comparatively high. The proportions of iron oxide and aluminium oxide are nearly equal. Phosphoric acid and nitrogen are both low, but other important plant-food ingredients, such as lime and potash, are adequate from the point of view of dry crop cultivation. The experiments described hereafter were conducted on this type of soil which can be taken as a typical representative soil to be found throughout the tract.

VII. Plan and equipment of the experimental plots

The area of the experimental plots was surveyed and the levels were determined at a distance of every 5 ft. The major slope was found to be in the north-westerly direction and the lay-out of the experimental plots therefore was fixed in the same direction. Eight unit plots were laid out. The size of each unit plot was fixed at ½ *guntha* or 1/80th of an acre for seven plots, the shape being a long narrow rectangle having its breadth and length in the proportion of 1 : 8. In the case of the eighth plot, the length was 16 times the breadth and the size of this plot was one *guntha* or double that the others. The average slope of all plots was 1·18 per cent (fall of 1 in 84). As the length of each of the seven plots was 66 ft., the total vertical fall in each plot was 0·78 ft. In the eighth plot, the length was 132 ft. and the total vertical fall from top to bottom was 1·56 ft. Each plot was surrounded on three sides by galvanized iron sheets 18 in. wide, half of which were buried in the ground and fixed by means of stout iron stakes at a distance of 4 ft. apart. The fourth and lower side of each plot was open and was level with the top of the side wall of a series of masonry tanks constructed at the lower end of each plot to catch the run-off of rain water and silt. Each tank had a flat bottom. Seven of these masonry tanks had dimensions of 8 ft. × 3·3 ft. × 3 ft., while the eighth one was 8 ft. × 5 ft. × 4 ft. An outlet pipe was provided in each tank which could be opened or closed as required. The ground-plan of the eight experimental plots and the tanks is shown in Fig. 2. All the outlet pipes opened into a drain whence the water from the tanks could be allowed to escape through an underlaid china pipe of 4 in. diameter to outside the experimental area. Plates XXXI and XXXII illustrate the general arrangement of the experimental plots and the tanks.

VIII. Treatment of the experimental plots

The undernoted eight treatments were given respectively to the eight plots mentioned above.

Plot 1 : *Retention of natural vegetation or sod* (*Treatment 1*)

This plot was kept unstirred and in its original condition, i. e. covered with the usual annual flora which was rather sparse at the commencement of the experiment. This vegetation was allowed to grow and develop naturally during the monsoon and to dry up during the hot weather months. During the five years' experimental period, the whole plot became completely covered with vegetation. In the hot weather, much of this vegetation dried up, but generally sprouted again during the monsoon. The most common species of plants present were : *Cynodon dactylon*, *Ischaemum pilosum*, *Euphorbia*

A general view of plots for run-off and soil erosion experiments at Sholapur

Some of the run-off plots with tanks

hyperecifolia, *Justicia quinquangularis*, *Tridax procumbenx*, *Tephrosia purpurea*, *Indigofera linifolia*, *Merremia emarginata*, *Panicum isachne*, *Panicum ramosum*, *Iseilema anthophoriodes*, *Cocculus villosus*, *Euphorbia dracunculoides*, etc.

Plot No.	Treatment	Plot No.	Treatment
1	Weeds preserved	5	'Scooped'
2	Weeds removed	5	*Kharif* crop of *bajri* and *tur*
3	Harrowed only	7	Ploughed and harrowed
4	*Rabi* crop of *jowar*	8	Ploughed and harrowed with double length

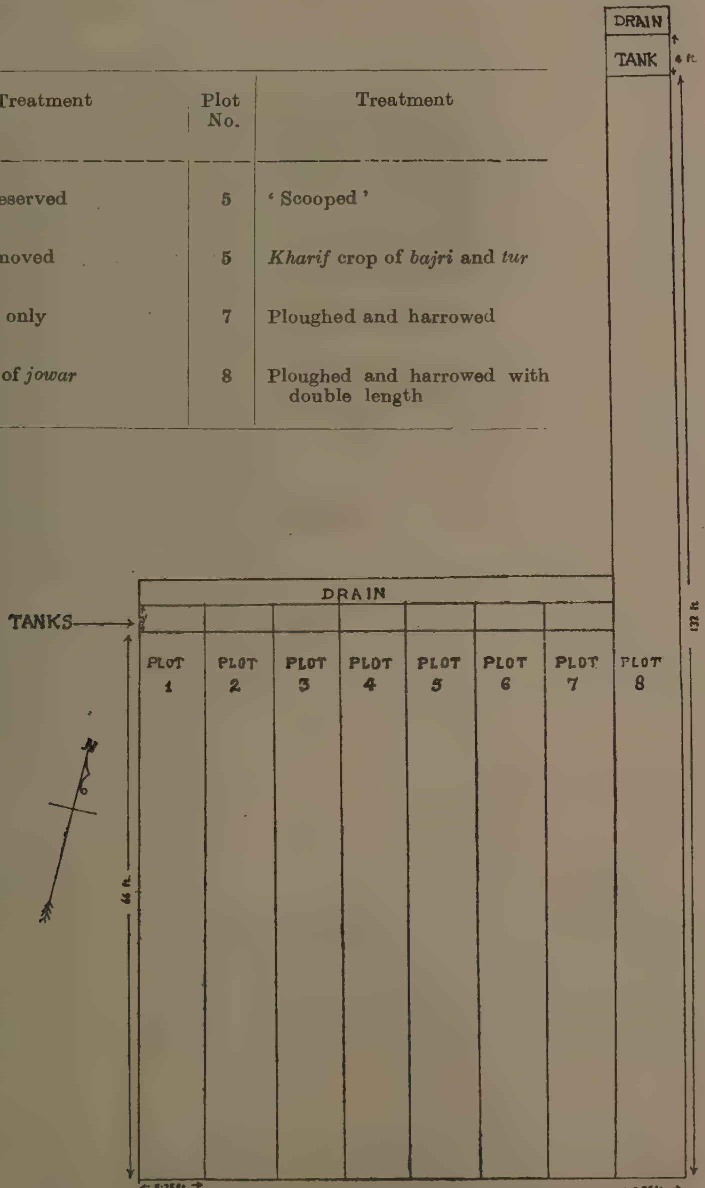

FIG. 2. Plan of the run-off and erosion experiments at Sholapur

Plot 2 : Removal of natural vegetation by cutting (Treatment 2)

The natural vegetation on this plot was superficially removed by cutting close to the ground without disturbing the surface soil. This was done annually, two or three times during the monsoon, whenever the vegetation had grown enough (one to two inches above ground) to interfere with the run-off.

Plot 3 : Shallow cultivation by local harrow (Treatment 3)

This plot received only such cultivation as is usually given by cultivators in the tract. Such cultivation is shallow and, for this purpose, the country blade harrow is the common implement used by the cultivator. The plot was harrowed to a depth of 4 in. two or three times during the season, once in the hot weather before the monsoon (May-June) and twice during the monsoon (July-September) before the sowing season.

Plot 4 : Cultivation of a rabi *crop of* jowar *(Treatment 4)*

In this plot, ploughing was done in the hot weather and subsequent harrowing was done every month from May to September. In the first year, the ploughing was carried out with a CT2 plough but, in the succeeding four years, the plot was hand-dug in order to get the effect of ploughing as actual ploughing was found to be impossible on account of the iron sheets fixed along the borders of the plots. A *rabi* crop of *jowar* (*Andropogon sorghum*) was sown at the beginning of October and received about four interculturings at an interval of about three weeks during November-January.

Plot 5 : Cultural treatment with a 'scooper' (Treatment 5)

The 'scooper' is a specially devised bullock-drawn implement which makes a number of shallow hollows or pockets when worked over a well-prepared soil. By the use of this implement, about 150 'scoops' or hollows were made over the surface of the plot, the intention being that the rain water should be held in these 'scoops' and run-off checked. The size of each hollow or 'scoop' was about 15 in. $\times$ 9 in. $\times$ 3 in. and the space between two 'scoops' was about 12 in. The scooping was done on two occasions, once early in July and again late in August.

Plot 6 : Cultivation of a kharif *crop of* bajri *and* tur *(Treament 6)*

After a thorough preparatory tillage consisting of one ploughing and two harrowings, this plot was sown with *bajri* (*Pennisetum typhoideum*) and *tur* (*Cajanus indicus*) mixture every year. In sowing this mixture either in June or July, the usual cultivators' practice of sowing three rows of *bajri* and the fourth row of *tur* was followed. The rows ran across the slope so as to obtain the fullest effect of the standing crop in checking rainfall run-off and soil erosion. Four to five interculturings were given to the standing crop at an interval of three or four weeks during July-October.

Plot 7 : Thorough and intensive preparatory tillage (Treatment 7)

In this plot, intensive preparatory tillage was given, which consisted of deep ploughing in the hot season and harrowing four times during the monsoon

from June to September. In the first year, the ploughing was done with a CT2 plough, but later on the plot was hand-dug to imitate ploughing. The furrows were made across the slope. No crop was cultivated.

Plot 8 : Treatment 7 on a plot double the length of plot 7 (Treatment 8)

This plot received similar treatment as was given to plot 7, i.e. intensive preparatory tillage consisting of ploughing and four harrowings. In this plot the effect of the greater length of the plot on the run-off and erosion was under study as the length of this plot was 132 feet, or double that of plot 7 and other plots.

NOTE.—Treatment 4 was carried out on plot 7 in the first year of the experiment and treatment 7 on plot 4 but, during the remaining four-year period, treatment 4 was continuously on plot 4 and treatment 7 on plot 7. The reason for this change was to avoid the sheltering effect of the standing crop of *bajri* and *tur* of plot 6 on the *jowar* crop of plot 7, as laid out in the first year. As plot 6 was to the west of plot 7, the standing crop on the former plot used to intercept the showers of the south-west monsoon and thus affect the growth of the *jowar* crop on plot 7.

IX. Measurement of the run-off water and the results obtained from June 1934 to May 1939

The experimental work started on 1 June 1934, when the construction of the tanks and the lay-out of the eight plots were completed.

Whenever run-off of rain water took place, measurements of the depth of the accumulated water in each plot-tank were taken as accurately as possible, an average of six readings correct to a tenth of an inch being calculated. The volume of water was then calculated on the basis of the known tank dimensions after making correction for the rainfall received directly into the tank. The water in each tank was then thoroughly agitated by stirring, and allowed to escape through the outlet near the bottom of the tank. A sample of this water was taken in a Winchester bottle, care being taken to obtain a fair sample. The quantity of suspended silt was determined in the laboratory by filtering the water through a filter paper and then by drying and weighing the residual material. The actual volume of water was then calculated by deducting the calculated volume of silt from the combined volume of water and silt. The amount of run-off from each plot was calculated both as cubic feet of water collected in each tank and as inches of rainfall lost. The results obtained over five years are given in Table V, which shows the equivalent inches of rain water lost by run-off annually from each of the eight plots receiving the different treatments described above.

On account of the expensive nature of the lay-out required for these experiments, they were conducted on single plots only. It will be shown in Appendix II by the analysis of variance that variation between plots is extremely small when the data of plots similarly treated over some period are worked out statistically.

X. Rainfall at Sholapur during the period of the experiment

Before discussing the results of the experimental work on run-off, it is necessary to examine how the rainfall varied during the experimental period of five years and how far it represented the average rainfall obtained in this tract over a prolonged period, both with regard to the total annual rainfall and its monthly distribution.

In Table VI, data regarding monthly and annual rainfall at the Research Station along with the number of rainy days are given. In column 2 of this table, the average monthly and annual rainfalls for a period of 25 years from 1908 to 1933, i.e. just prior to the commencement of the experiments, are given. Columns 3-7 give similar data for the five years of the experiments, while in the last column, the average monthly and annual rainfalls and the number of rainy days for the whole period of five years (1934-39) are given along with their deviations from the annual average. It may be seen, by comparison of columns 2 and 8, that the average annual rainfall for the shorter period of five years was practically the same as the annual average over the longer period. The average distribution differed, however, in the two periods. The average rainfall of the three months from June to August was somewhat higher during the shorter period than during the longer period. On the other hand, the rainfall during September and October was somewhat lower during 1934-39 than during the previous 25 years' period, i.e. from 1908 to 1933. The number of rainy days per annum did not differ much. Curves showing the average monthly distribution during the two periods readily illustrate the above points (Fig. 3). If the individual years are considered separately, then it can be seen that the years 1934-35 and 1936-37 were years of drought when only 80 and 60 per cent, respectively, of the annual average rainfall were received. The year 1937-38 received very nearly the annual average rainfall. The remaining two years, viz. 1935-36 and 1938-39, were wet years and received rainfall higher than the annual average. This increase, however, was only 20 per cent in the former year but was nearly 40 per cent in the latter. In the year 1938-39, the number of rainy days was also much higher, viz. 57 as against the normal average of 41·2. It can be seen therefore that the period of experimentation may be taken as fairly typical in covering possible variations in individual years and, at the same time, giving approximately average rainfall conditions over the total period of five years similar to those experienced over a long period of 25-30 years. Fig. 4 indicates the variation in the monthly distribution of rainfall during the five years of the experimental work. It can be seen from the data in Table VI that no exact relationship appears to exist between the number of rainy days in a year and the total rainfall received during the same period. Although it is true that in general the higher the number of rainy days, the greater the total rainfall and *vice versa*, this is not always the case. Thus, in the year 1937-38, the rainfall was nearly 25 per cent higher than that of 1934-35, but the number of rainy days was smaller, viz. 42 in the former year as against 46 in the latter year. Again the year 1935-36 received nearly 40 per cent more rain than the year 1934-35, but the total number of rainy days in both the years was exactly the same.

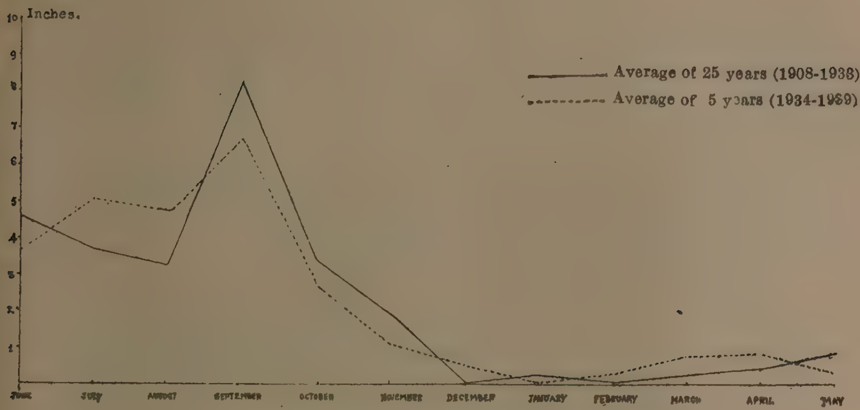

FIG. 3. Average rainfall at Sholapur

TABLE V

Quantities of water lost by rainfall run-off in inches from each plot during the five years of experiment

No. of plot	Treatment	Rainfall lost in inches				
		June 1934—May 1935	June 1935—May 1936	June 1936—May 1937	June 1937—May 1938	June 1938—May 1939
1	Retention of natural vegetation .	0·21	4·02	0·07	0·65	0·64
2	Natural vegetation removed by cutting	1·37	5·80	1·06	6·36	9·48
3	Shallow cultivation by harrowing .	1·24	5·70	2·22	8·36	9·51
4	Thorough and intensive cultivation by ploughing and harrowing and growing *rabi* crop of *jowar*	1·09	5·55	1·89	7·47	6·92
5	'Scooping' of the surface soil after thorough cultivation	0·02	3·83	0·19	4·32	2·01
6	Thorough cultivation by ploughing and harrowing and growing *kharif bajri* and *tur* mixture	0·58	4·62	1·58	6·99	4·41
7	Thorough and intensive cultivation by ploughing and harrowing	1·42	5·02	1·93	7·14	6·41
8	Thorough and intensive cultivation as in plot 7 with double length	1·21	5·31	2·10	7·74	6·30

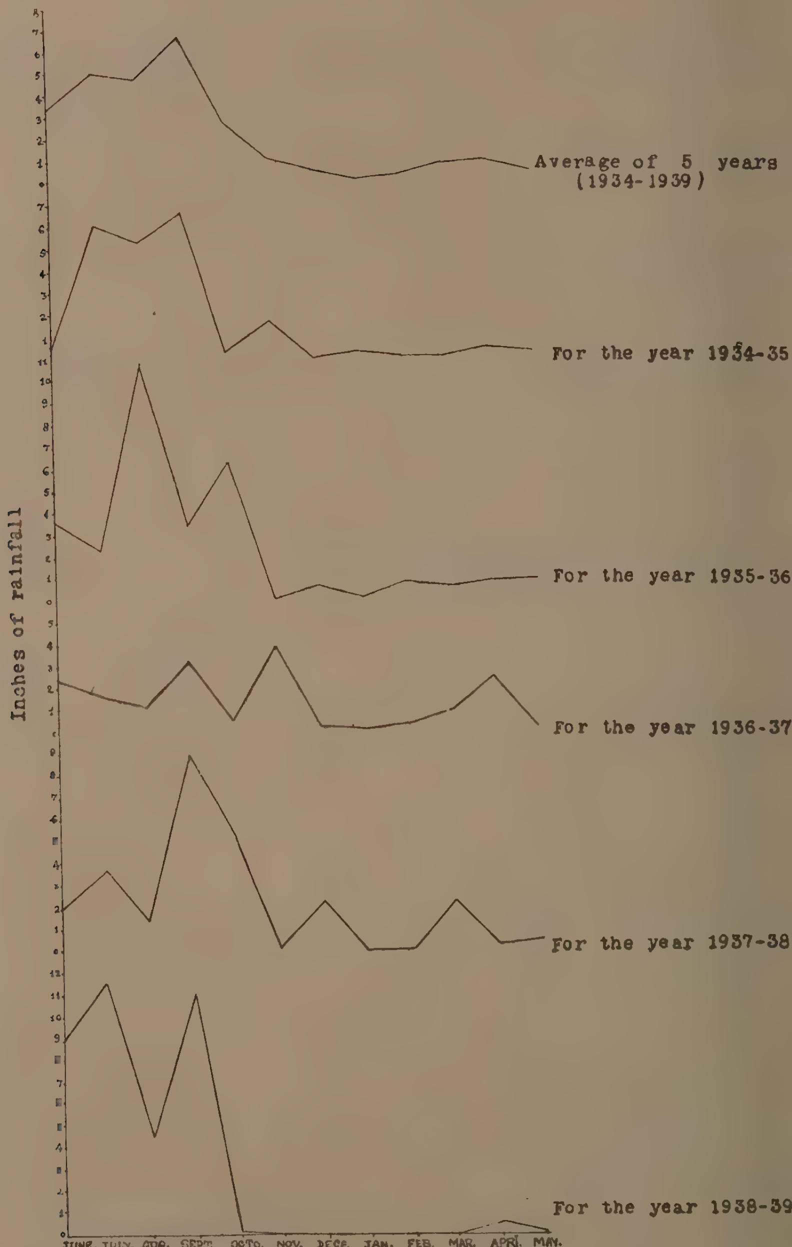

FIG. 4. Average monthly rainfall at Sholapur during the experimental period

TABLE VI

Rainfall and the number of rainy days at Sholapur

Calender months	Average for 25 years		1934-35		1935-36		1936-37		1937-38		1938-39		Average for the years 1934-39	
	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days
June	4·55	6·6	0·59	3	3·54	10	2·43	4	1·92	2	8·45	13	3·39	6·4
July	3·70	7·7	6·06	13	2·26	6	1·62	5	3·65	12	11·59	19	5·04	11·0
August	3·15	7·6	5·33	9	10·84	11	1·10	3	1·53	4	4·53	12	4·67	7·8
September	8·10	9·0	6·56	12	3·44	6	3·12	5	8·96	11	11·02	9	6·62	8·6
October	3·30	4·3	0·28	2	6·39	7	0·47	1	5·12	5	1·06	2	2·66	3·4
November	1·75	1·5	1·62	3	0·01	...	3·75	3	...	...	...	...	1·08	1·2
December	Trace	0·6	...	...	0·56	1	0·05	...	2·08	3	...	...	0·54	0·8
January	0·15	0·3	0·19	1	...	...	...	...	...	...	...	...	0·04	0·2
February	...	...	...	...	0·73	2	0·23	1	...	...	...	...	0·19	0·6
March	0·20	0·4	...	...	0·36	1	0·75	2	2·21	2	...	...	0·66	1·0
April	0·40	1·0	0·41	2	0·65	1	2·40	4	0·23	1	0·49	2	0·84	2·0
May	0·75	2·2	0·11	1	0·74	1	...	...	0·41	2	...	...	0·25	0·8
TOTAL	26·40 ±1·53	41·2	21·15	46	29·52	46	15·92	28	26·11	42	37·14	57	25·96 ±3·62	43·8 ±0·09

Similarly, monthly rainfall is not always proportional to the number of rainy days in the month. This is due to the fact that the intensity of rainfall is different in different months, as can be seen clearly from the figures given in the last column of Table VI. It can be stated in general that the intensity of rainfall is greater in the latter half of the monsoon, i.e. from September to November, than in the first half, i.e. from June to August. The month of July gave the largest average of rainy days but the intensity of rainfall in this month was the lowest. It should be noted that the rainfall during the period of September to November is generally received in the shape of stormy downpours lasting for only an extremely short period of one to two hours daily. The rainfall during the early period of the monsoon is generally received as small showers of a persistent and soaking nature, lasting over a large number of hours each day. This shows that the early monsoon rains are generally of low intensity while those of the later period are of great intensity. This intensity of rainfall has a very great bearing on the run-off of rain water and on consequent soil erosion.

XI. Temperatures, humidity and wind velocity at Sholapur

Mention has already been made of the influence of climatic factors, other than rainfall, on the run-off of rain water and on consequent soil erosion. In Table VII monthly average values for some of the more important meteorological observations taken during the experimental period of five years, i.e. 1934-35 to 1938-39 are given.

Table VII

Monthly averages of important meteorological observations at Sholapur Dry Farm

(Average of 5 years from 1934-35 to 1938-39)

Month	Maximum temperature (°F.)	Minimum temperature (°F.)	Mean temperature (°F.)	Relative humidity per cent	Wind velocity miles per hour	Evaporation from free water surface in inches
June	94·23	73·35	83·79	73·94	10·78	11·79
July	88·43	70·94	79·65	82·34	10·40	8·61
August	88·15	70·02	79·10	81·03	9·43	8·17
September	86·84	69·53	78·19	82·40	7·31	7·80
October	90·04	66·53	78·30	65·79	5·78	10·77
November	86·17	58·82	72·50	58·94	5·04	8·63
December	84·28	55·93	70·12	58·99	4·44	8·66
January	86·47	56·96	72·62	55·30	4·13	9·94
February	90·78	60·65	75·72	47·57	4·72	10·81
March	97·90	67·33	82·52	34·97	5·12	16·30
April	101·06	72·37	86·73	40·90	6·05	17·22
May	105·41	76·44	90·93	43·57	7·72	20·43

The data of monthly average maximum and minimum temperatures indicate the wide range of temperatures prevailing in this tract. The very high temperatures during April and May result in considerable sun-drying and baking of soils, which causes considerable cracking and fissure formation in the deeper types of soils. These cracks ultimately give rise to gully formation as a result of the run-off of heavy rains at the outbreak of the south-west monsoon. The higher temperature of the atmosphere, combined with the high wind velocity during the monsoon months, produces a highly desiccating effect on the soils. Slight showers are, at that time, ineffective as the soil moisture is largely lost by evaporation during the following 24 hours. The high rate of evaporation of water noted from free water surface indicates a similar trend of rapid evaporation of soil-moisture. These factors result in the surface soil remaining dry and pulverized, thus facilitating its removal by the run-off water resulting from the heavy showers commonly received in September and October in this tract. The knowledge of the influence of such climatic factors facilitates a clearer understanding of the experimental results on run-off and soil erosion which are discussed hereafter.

XII. Results of rainfall run-off experiments at Sholapur

(*A*) *Effect of experimental treatments*

The eight different treatments given to the eight plots in the experimental area have already been mentioned in detail. The main object of these different treatments was to ascertain whether any particular method of tillage or cultivation or the growing of any particular crop would have a controlling effect on the quantity of water lost by run-off. The results of the experiments given in Table V were obtained from the estimate of the actual volume of water lost from the area of 1/80th or 1/40th of an acre in cubic feet from year to year and are expressed in inches of rainfall thus lost. Table VIII shows the number of occasions upon which run-off of rain water took place in each year and also the total number of such run-offs during the five years under each plot treatment. The quantities of water lost from each plot in inches are also shown. Careful scrutiny of these results shows that the treatment on plot 1, viz. the plot with natural vegetation preserved *in situ* gave the lowest number of run-offs and lost the smallest quantity of rain water by run-off during the experimental period of five years. In this plot, there were, in all, 23 run-offs during the five years and the total quantity of rain water lost in this way amounted to 5·59 in. during the same period. This treatment was, therefore, the most effective in checking the loss of rain water by surface run-off. The treatment given on plot 5, which consisted of 'scooping', ranked second in effectiveness in controlling run-off. The number of run-offs on plot 5 during five years was 31 or nearly 25 per cent more than on plot 1, but the total quantity of rain water lost amounted to 10·37 in., which is nearly 85 per cent more than the loss on plot 1. Only one more treatment, viz. the cultivation of *bajri* and *tur* crops on plot 6 showed some appreciable effect in controlling rain water run-off. The number of run-offs in this plot was 43 and the water lost amounted to 18·28 inches. If, however, the results from plot 6 are compared with the results obtained on plot 1, i.e. vegetation cover, the number of run-offs on the former plot was nearly double

TABLE VIII

Number of run-offs from each plot and inches of rainfall lost from each plot in different years

Year of observation	Plot 1 Retention of vegetation		Plot 2 Removal of vegetation		Plot 3 Shallow cultivation		Plot 4 Cultivation of *rabi jowar*		Plot 5 'Scooping'		Plot 6 Cultivation of *kharif bajri* and *tur*		Plot 7 Thorou gh cultivation		Plot 8 Thorough cultivation and double-length	
	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)	No. of run-offs	Rainfall lost by run-offs (In.)
1934-35	5	0·21	5	1·37	5	1·24	5	1·09	4	0·02	6	0·68	6	1·42	5	1·21
1935-36	6	4·02	9	5·80	9	5·70	8	5·55	6	3·83	6	4·62	7	5·02	6	5·31
1936-37	3	0·07	5	1·06	5	2·22	4	1·89	3	0·19	3	1·58	4	1·93	4	2·19
1937-38	7	0·65	16	6·36	20	8·36	16	7·47	11	4·32	15	6·99	16	7·14	15	7·74
1938-39	2	0·64	15	9·84	15	9·51	13	6·92	7	2·01	13	4·41	13	6·41	13	6·30
Total in 5 years	23	5·59	50	24·43	54	27·03	46	22·92	31	10·37	43	18·28	46	21·92	43	22·75
Average per annum	4·6	1·12	10	4·88	10·8	5·40	9·2	4·58	6·2	2·07	8·6	3·65	9·2	4·38	8·6	4·55

that on the latter and the quantity of water lost more than three times. The *bajri* crop stands for 3-3½ months during the south-west monsoon period and the *tur* crop remains much longer. The combined effect of these standing crops in checking run-off can be seen in the results obtained on plot 6 if compared with those of plot 7.

The treatment given in plot 2, where the natural vegetation was removed by cutting close to the soil surface without disturbing the soil itself, showed by contrast the great preserving effect on soil erosion of the plant cover on plot 1. The soil in both cases was undisturbed, but there was a vegetation cover in plot 1 and no such cover in plot 2. Treatment on plot 2 gave in all 50 run-offs and lost a total of 24·43 inches of water during the five years. The number of run-offs was more than double that on plot 1 during that period and the rain water lost by run-off on plot 2 was more than four times that lost on plot 1 which had plant cover. It was observed that this plot used to get dry and crack extensively during the hot weather. This cracking facilitated the vertical percolation of rain water and thus reduced the loss of rain water by surface run-off.

The treatment on plot 3 consisted of shallow cultivation, viz. two or three harrowings during the monsoon months done with a blade harrow. This plot gave the largest number of run-offs, viz. 54 and also lost the largest total quantity of rain water, viz. 27·03 in., during the complete period of five years. The difference of 2·6 inches in the total water lost by run-off between plots 2 and 3 was mainly due to higher loss from plot 3 in one year. During the year 1937-38 which gave a greater number of intensive showers, there were four additional run-offs and 2 in. excess loss of rain water from plot 3 as compared to plot 2. That the difference between the treatments on plots 2 and 3 is not statistically significant, is shown later on in another statement.

The treatment on plots 7 and 8 consisted of thorough and intensive cultivation of the land by one deep ploughing in the hot season, followed by four or five harrowings during the monsoon months. The length of plot 8 was double that of plot 7. The total number of run-offs during five years was 46 from treatment on plot 7 and 43 from treatment on plot 8. The total quantity of water lost was 21·92 in. and 22·75 in. from plot 7 and plot 8 respectively. As compared to no cultivation on plot 2, or shallow cultivation on plot 3, the run-off was somewhat lower in the case of the deeper cultivation on plots 7 and 8. There was no noticeable difference due to the different lengths of the two plots. This is contrary to the result obtained by Duley and Ackerman [1934] in the U. S. A. They found that the shorter plots gave a larger percentage of surface run-off than longer plots. Thus, although the thorough and deep cultivation given effected a slight reduction in the number of run-offs, and in the quantities of water lost by run-off, when compared with the treatment on plot 3 which received shallow cultivation and also with treatment on plot 2 which received no cultivation, the difference was not statistically significant. Miller and Krusekopf [1932] found no benefit as a result of deep ploughing in checking the surface run-off of rain water.

The remaining treatment on plot 4 consisted of thorough and intensive cultivation, as in plots 7 and 8, and had in addition a *rabi* crop of *jowar* from

October to February. The total number of run-offs during the five years from the plot was 46 and the total quantity of water lost amounted to 22·92 in. Thus there was no apparent influence of the cultivation of a *jowar* crop on the rain-water run-off. This may be attributed to the fact that most of the rains were received before the sowing of the crop and only a small amount during the very early stage of the crop when the young seedlings could not in any way influence the run-off. Fig. 5 illustrates the comparative losses of water every year under different treatments.

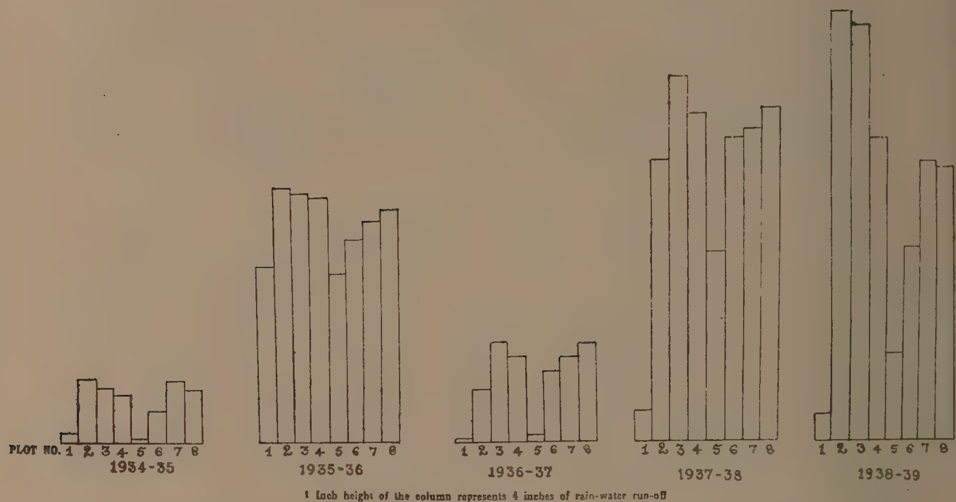

FIG. 5. Relative quantities of rain water in inches lost by run-off from plots under different treatments

[Plot 1, weeds preserved ; plot 2, weeds removed ; plot 3, harrowed only ; plot 4, *rabi* crop of *jowar* ; plot 5, scooped ; plot 6, *kharif* crop of *bajri* and *tur* ; plot 7, ploughed and harrowed ; plot 8, ploughed and harrowed with double length]

Thus, to sum up the results of the experimental work on the effect of the different treatments on rain-water run-off, it can be stated that: (1) There is some reducing effect resulting from deep cultivation on the number of run-offs and on the quantity of rain water lost by run-off as compared to the effects of shallow or no cultivation. The results of treatments on plots 2, 3 and 7 suggest the above conclusion. (2) The length of the plot does not affect the run-off materially as seen from the comparison of the results of treatments on plots 7 and 8. (3) The cultivation of *rabi jowar* also had no influence on the run-off. (4) The cultivation of a mixed crop of *bajri* and *tur* in the *kharif* season reduced the quantity of water lost by run-off. (5) The special cultural treatment of 'scooping' reduced both the number of run-offs and the total quantity of water lost by run-off. (6) The most effective treatment in controlling and reducing the rainfall run-off was found to be the conservation of the natural vegetation on the untouched surface of the soil.

(*B*) *The total annual rainfall, the number of days on which run-off occurred and the quantity of rain water lost by run-off during the experimental period of five years*

Having considered the effect of different cultural treatments and systems of cropping on the quantity of rain water lost by run-off in the preceding paragraphs, it will be interesting to see whether any relationship can be traced between the total annual rainfall and the number of days on which run-off occurred as well as the total quantity of rain water lost by run-off during the same period.

TABLE IX

Total annual rainfall, the number of days on which run-off took place and the total quantity of rain water lost by run-off

Year	Total rainfall during the year in inches	The number of days on which run-off occurred	The total quantity of rain water lost by run-off in inches
1934-35	21·15	5	1·24
1935-36	29·52	9	5·70
1936-37	15·92	5	2·22
1937-38	26·11	20	8·36
1938-39	37·14	15	9·51

The data presented in Table IX are for treatment 3, i.e. shallow cultivation by harrowing on plot 3. The data from this plot are selected for consideration as this treatment represents closely the usual cultivation followed by the cultivators in the tract.

Careful scrutiny of the figures in columns 2 and 3 would indicate that no relationship can be established between the total annual rainfall and the number of days on which run-off occurred during the year. This is illustrated by the fact that the year 1938-39, with the highest total rainfall (37·14-in.), was not the year which recorded the largest number of run-off days. On the other hand, the year 1937-38, with only 26·11 in. total rainfall, recorded the largest number of days on which run-off occurred. Similarly the total quantity of rain water lost by run-off during the year is not proportional to the total rainfall received during the same period. This can be clearly seen by comparison of the data for the year 1934-35 with those for 1936-37 and again the data for the year 1935-36 with those for 1937-38. Thus the number of days on which run-off occurred and the total quantity of water lost by run-off bear no definite proportional relationship to total annual rainfall. Other factors in this connection are considered later.

(*C*) *Monthly rainfall, number of days on which run-off occurred and the total rainfall run-off from month to month during the experimental period*

The average number of days upon which run-off occurred in each month is shown in Table X for the whole period of five years for the treatment on plot 3, i.e. treatment 3, viz. shallow cultivation by harrowing. It will be seen that the maximum number of days of run-off was recorded in the month of September with an average of 3·2. July stood second with 2·2 days of run-off and August third with 1·8. The month of June recorded 1·6 days of run-off followed by October with an average of one day of run-off. The remaining seven months together recorded only 1·2 days of run-off. The average quantity of water lost generally increased from June to September and rapidly decreased from October to December. The remaining months. except March, recorded no run-off. The quantity of water lost by run-off was much higher in September and was equal to the total quantity lost during the three months of June, July, and August. The differing effects on rainfall run-off of the early rainfall (June-August) and the later (September and October) can be seen from the detailed consideration of the data presented in Table X. Thus, in the year 1934-35, the month of July recorded 6·06 in. of rainfall and the month of September, 6·56 in. But there was only very slight run-off equal to 2 cents of rainfall in July, while in September a loss of 1·20 inches occurred on three occasions. Examples can be multiplied to show that there is no exact relationship between the monthly rainfall and the quantity of rain water lost by run-off during the month. Detailed considerations of the experimental data for five years indicate that, for a given slope and type of soil, the most important factors that influence rainfall run-off appear to be : (1) the intensity of individual showers and (2) the moisture-status of the soil previous to the rainfall resulting in run-off. Both these factors are considered in detail in Table X.

(*D*) *Intensity of showers and rainfall causing run-off*

Appendix I-*a* shows the rainfall recorded on all rainy days in each month. The figures representing rainfalls that caused surface run-off from any of the experimental plots have been shown in italics. The data for all the five years of the experiments have been included in that table. In addition, the rainfalls have been grouped into four classes indicating varying intensities according to the quantity of rainfall received during a day or 24 hours. These data have been summarized in Table XI, which gives the total number of rainfalls in each class for each year and the number of rainfalls in each class which caused surface run-off.

It can be seen from Table XI that the total number of rainy days was 218 during the whole period of five years. Out of this total 55, or nearly 25 per cent of the total number, caused surface run-off. Only nine, or nearly 4 per cent of the total number, exceeded 2 inches of rainfall. Twenty-five, or 11·4 per cent varied from 1 in. to 2 in. Forty, or 18·3 per cent, varied from ½ in. to 1 in., while the remaining 144, or nearly 66 per cent, represent less than ½ in. rainfall in a day. Detailed examination of these data as presented in Table XI reveals an interesting relationship between the intensity of rainfall and the occasions of rainfall run-off.

TABLE X

Monthly distribution of rainfall, the number of days of rainfall run-off, and the quantity of water lost by run-off

(Plot 3)

Month	1934-35			1935-36			1936-37			1937-38			1938-39			Average of 5 years		
	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches	Rainfall in inches	No. of run-offs	Quantity of water lost in inches
June	0·59	...	...	3·54	1	0·05	2·43	...	...	1·92	2	0·69	8·45	5	2·56	3·38	1·6	0·66
July	6·06	1	0·02	2·26	1	0·01	1·62	1	0·04	3·65	3	0·23	11·59	5	2·39	5·07	2·2	0·54
August	5·33	2	0·02	0·84	6	4·34	1·10	...	...	1·53	1	0·08	4·53	...	...	4·56	1·8	0·89
September	6·56	3	1·20	3·44	...	...	3·12	2	0·76	8·96	6	3·93	11·02	5	4·56	6·62	3·2	2·09
October	0·28	...	...	6·39	1	1·30	0·47	...	...	5·12	4	1·78	1·86	...	...	2·66	1·0	0·61
November	1·62	...	...	0·01	...	...	3·75	2	1·42	...	...	...	...	...	...	1·08	0·4	0·28
December	...	...	...	0·56	...	...	0·05	...	...	2·08	3	1·07	...	...	...	0·54	0·6	0·22
January	0·19	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0·4	...	...
February	...	...	...	0·73	...	...	0·23	...	...	...	...	...	...	...	...	0·19	...	...
March	...	...	...	0·36	...	...	0·75	...	...	2·21	1	0·58	...	...	...	0·66	0·2	0·11
April	0·41	...	...	0·55	...	...	2·40	...	...	0·23	...	...	0·49	...	...	0·84	...	...
May	0·11	...	...	0·74	...	...	...	...	...	0·41	...	...	...	...	...	0·25	...	...
Total	21·15	6	1·24	29·42	9	5·70	15·92	5	2·22	26·11	20	8·36	37·14	15	9·51	25·96	11	5·40

TABLE XI

Classification of rainfall according to intensity and the number of rainfall run-offs in each class, during the experimental period

Year		0—50 cents	50—100 cents	1—2 inches	More than 2 inches	Total	Remarks
1934-35 . . .	No. of rainfalls in each class	36	4	4	2	46	
	No. of rainfalls that caused run-off	2*	...	2	2	6	*Sharp showers on previously saturated soil
1935-36 . . .	No. of rainfalls in each class	28	12	3	2	45	
	No. of rainfalls that caused run-off	1*	2†	3	2	8	†Showers were either of great intensity or were received on saturated soil
1936-37 . .	No. of rainfalls in each class	18	7	2	1	28	
	No. of rainfalls that caused run-off	1*	2†	1	1	5	
1937-38 . . .	No. of rainfalls in each class	26	8	6	2	42	
	No. of rainfalls that caused run-off	6*	6	6	2	20	
1938-39 . . .	No. of rainfalls in each class	36	9	10	2	57	
	No. of rainfalls that caused run-off	2*	3	8	2	15	
Total for five years .	No. of rainfalls in each class	144	40	25	9	218	
	No. of rainfalls that caused run-off	12*	14	20	9	55	
	Percentage of the number of rainfalls that caused run-off	8·3	35	80	100	25·2	

It can be seen that: (*a*) all the nine showers of more than 2 in. resulted in surface run-off of rain water; (*b*) 20 rainfalls, or 80 per cent of the rainfalls varying from 1 in. to 2 in., also resulted in surface run-off. Five rainfalls belonging to this class, which did not result in run-off, were received as 'soaking' and intermittent rainfalls spread over the 24 hours. In some cases, however, they were solitary showers during the dry season from November to May; (*c*) about 35 per cent, or 14 out of 40 rainfalls belonging to the class of ½ in.-1 in., resulted in surface run-off. These were sharp showers of considerable intensity usually precipitated in less than one hour; (*d*) of the remaining 144 rainfalls (belonging to the class with less than 50 cents a day) only 12 rainfalls, or 8·3 per cent, resulted in run-off. The average rainfall of the 12 showers causing run-off in this class was, however, 35·8 cents. All these showers were of great intensity and were received on already saturated soil surface. The smallest shower producing run-off in this class was one of 17 cents, and was received in continuation of the previous day's rainfall on an already saturated soil surface.

(*E*) *Moisture status of the soil previous to the occurrence of rainfall run-off*

Consideration of the data given in Appendix I-*a*, in addition to those summarized in Table X, reveals that, in general, the number of days of run-off was higher in the latter part of the monsoon season. But, more particularly, the quantity of water lost by run-off was distinctly greater during the period from September to November than during the period of June to August. It has been shown in the preceding paragraph that this is due partly to the greater intensity of the showers in the latter part of the monsoon. But another very important factor which contributes to

run-off is the moisture status of the soil previous to the rainfall causing such run-off. At the commencement of the monsoon in June, the surface 12 in. layer of soil of the arable lands in the tract is very dry. Moisture in such soils gradually increases from June to August and usually reaches saturation point in August or September. This may be seen from the data of soil-moisture content for the two seasons of 1934 and 1935 given in Table XII.

TABLE XII

Change of soil moisture from month to month (per cent)

1934			1935		
Dates	Surface layer 0—6 in.	Sub-surface layer 6 in.—12 in.	Dates	Surface layer 0—6 in.	Sub-surface layer 6 in.—12 in.
5 March	12·45	21·61	4 May	7·76	20·14
9 April	29·92	23·04	4 June	6·60	19·33
4 July	23·85	25·47	5 August	19·89	16·29
4 August	41·43	39·49	5 September	38·14	39·41
13 September	36·80	41·44			

When the land is fairly level and the soil is dry and porous, the rain water first moistens the dry soil and then percolates vertically downwards. When the surface-soil layer has become saturated, the rain water begins to run over the surface along the direction of the slope. The deeper types of soil in the Sholapur district have a high field capacity or a high saturation point, holding nearly 40-44 per cent moisture by weight. The surface layer of 12 in. can easily hold 6-7 in. of rain water and run-off would generally begin only after this saturated condition has been reached at least in the surface layer. Hence the number of run-offs in June, July and August is usually very limited. But this normal behaviour is often upset by other factors, viz. the intensity of the showers, the slope of the land and the impervious nature of the soil. When showers of great intensity, such as those which yield 1-2 in. of rain in an hour, are received, run-off of rain water may take place even before the saturation of the surface layer. Similarly, when the slope of the land is relatively greater, the rain water may begin to move along the slope before the saturation of the surface layer is complete. The effect of intensive showers, especially on impervious soils, is to saturate and compact a thin layer of 1-2 in. on the surface and thus to obstruct vertical penetration of rain water, causing lateral movement of water along the sloping surface. The data of soil-moisture contents for 1934 and 1935, given in Table XII, show how the soil-moisture normally increases during the monsoon and saturates the soil either in August or in September, after which period by far the greatest quantities of rain water are lost as a result of surface run-off.

(*F*) *Percentage of the annual rainfall lost by run-off*

The quantities of rain water lost by run-off from year to year for any of the eight treatments indicated in Table VIII show tremendous variations from year to year. This variation has been shown to be due to the variation

in the annual rainfall, difference in monthly distribution of rainfall and variation in the intensity of showers. The same data are calculated as per cent of the total annual rainfall and are given in Table XIII.

TABLE XIII

Rainfall lost by run-off as per cent of the annual total for 1934-39

Year	Rainfall in inches	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
1934-35	21·15	0·99	6·47	5·86	5·15	0·09	3·21	6·70	5·70
1935-36	29·52	13·60	19·60	19·32	18·84	12·90	15·64	17·00	17·90
1936-37	15·92	0·43	6·60	13·94	11·85	1·19	9·92	12·12	13·70
1937-38	26·11	2·48	24·35	32·01	28·66	16·54	26·77	27·34	29·64
1938-39	37·14	1·72	26·49	25·60	18·63	5·41	11·86	17·24	16·92
Average of five years .	25·96	3·44	15·50	18·34	16·61	7·22	13·48	16·08	16·71

The examination of these figures indicates fairly consistent behaviour of most of the plots under different treatments in the majority of seasons. The average results of five years show that the percentage losses of rain water in two treatments, viz. that of untouched vegetative cover (plot 1) and of 'scooping' (plot 5), are distinctly lower, viz. 3·44 and 7·22 per cent of the average total annual rainfall although there is considerable seasonal variation. In the remaining six treatments, the average percentage losses vary from 13·48 to 18·34. The lower figure was obtained with the treatment of *bajri* and *tur* cropping (plot 6) and the largest for the treatment of mere shallow cultivation without any crop (plot 3). Miller and Krusekopf [1932] in their experiments found the run-off to vary from 12 to 30·7 per cent of the total rainfall. The percentage losses found at Sholapur appear therefore to be comparatively smaller than those recorded in the U. S. A.

(*G*) *Loss of rain water by run-off as per cent of the rainfall causing run-off*

It has already been shown that all rainfalls are not capable of producing run-off. Most of the run-offs are produced by rains of more than ½ in. in intensity. As the important crop in this tract (*jowar*) is grown in the *rabi* season on moisture resulting from the rainfalls during the early monsoon and conserved in the soil, only such of the rainfalls as can penetrate down into the lower layers of the soil can be considered as useful from the point of view of *rabi* cultivation. It has been observed that rainfalls of more than one inch received in 24 hours are of this type and nearly 80 per cent of such rainfalls usually produce run-off. Therefore, if the amounts of the rain water lost by run-off are calculated as percentages of the rainfalls causing run-off, the figures obtained indicate that a very high proportion of the agriculturally useful rainfalls are lost by run-off. Calculations on these lines, along with their deviations, are given in Table XIV.

Examination of the figures in Table XIV indicates more consistent behaviour as regards run-off of most of the plots in the majority of years. It can be seen that only two plots, viz. 1 and 5, which had the lower run-offs, show wide fluctuations. With the remaining plots under different treatments, the annual figure of run-off in four years out of five shows a close agreement

with the average figure computed for the total period of five years. In the first year of the experiment only, the results were much lower than the average figure on account of very favourable distribution of rainfall during that year. The average proportion of the water lost to the total rainfall causing run-off under most of the treatments is very high varying from 26 to 38 per cent in the six cultural treatments used in the experiments. This proportion in some years and under some treatments exceeded 44 per cent. This high loss of useful rainfall assists in explaining the occurrence of crop failures even in years with a total average rainfall.

TABLE XIV

Rainfall lost by run-off as per cent of the total rainfall causing run-off

Year	Total rain-fall causing run-off	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
1934-35 . . .	8·11	2·59	16·96	15·31	13·45	0·25	8·39	17·53	14·94
1935-36 . . .	14·77	27·21	39·26	38·59	37·58	25·93	31·37	33·98	35·95
1936-37 . . .	5·93	1·18	17·87	37·44	31·87	13·20	26·65	32·55	36·93
1937-38 . . .	19·38	3·35	32·82	43·13	38·54	22·29	36·07	37·10	39·93
1938-39 . . .	22·30	2·88	44·32	42·83	31·17	9·05	19·86	28·87	28·37
Average . .	14·09	7·93	34·65	38·34	32·51	14·71	25·93	31·09	32·27
	±3·15	±4·96	±5·97	±5·36	±4·62	±5·28	±4·88	±1·79	±4·53

XIII. LOSS OF SOLUBLE SALTS FROM SOILS IN RUF-OFF WATER

The quantities of the fertility elements removed in solution by run-off waters were determined in some years. The total salts and lime thus lost in run-off waters were determined in all years after every run-off. These data are given in Appendices I-*c* and I-*d*. Considering the data for plot 4, i.e. treatment 4, viz. cultivation of *rabi jowar* after intensive preparatory cultivation, the total soluble salts lost in a year show a variation of from 26·06 lb. to 234 lb. per acre during the five years. Soluble lime forms quite a substantial proportion of the total salt. This can be seen from data in Appendix I-*d*. The quantity of lime removed has varied, indifferent years, from 9·22 lb. to 91·18 lb. per acre, showing that it forms nearly 35-39 per cent of the total soluble salts.

The nitrogen content of all the run-off waters, both as nitric nitrogen and as ammoniacal nitrogen, was also determined in three seasons. The total quantity of nitrogen thus removed in solution was found to be very small in each of these years. The average quantity lost every year during this period varied in different plots from 0·13 lb. to 0·53 lb. per acre. The nitric and the ammoniacal forms of nitrogen were found in nearly equal proportions. The nitrogen received in the rain water every year was separately determined and deducted from the nitrogen obtained from the run-off waters.

Phosphoric acid removed in solution in the run-off waters was determined during 1936. The total quantity lost during the whole year was found to be very low, being only about ½ lb. per acre from plot 4, i.e. *rabi jowar* cultivation (treatment 4).

If the quantities of nitrogen and phosphoric acid lost in solution in run-off water are compared with similar figures for other countries, the Sholapur figures are found to be very low indeed. The quantities of phosphoric acid lost in similar experiments at the Missouri Experiment Station are much higher, viz. 47 lb. per acre in the uncultivated plot as compared to less than ½ lb. at Sholapur. Even the nitric nitrogen lost at Missouri exceeded 6 lb. per acre in the uncultivated plot. These low values at Sholapur are mainly due to the low initial fertility of the Sholapur soils, with regard to both nitrogen and phosphoric acid.

XIV. Results of soil erosion experiments at Sholapur

The loss of rain water by surface run-off is no doubt a considerable factor contributing towards crop failures in the Deccan tracts of precarious rainfall, but such loss of water is only temporary, being restricted in its effects to the season only. The con-comitant loss of soil that takes place with every run-off of rain water causes a serious permanent and accumulative damage to the land. The soil lost is lost for ever. The same factors which influence the run-off of rain water also influence soil erosion. Thus the cultivation given to the land, the total annual rainfall, the intensity of successive showers, the moisture-status of the soil, all have a direct influence on soil erosion as on rainfall run-off. It is not therefore necessary to consider these factors again in detail. The experiments to determine the losses of rain water by run-off, described hitherto, were simultaneously utilized to determine the quantities of silt lost under different methods of cultivation or treatment. The exact quantities of silt lost during the five years from the plots under varying treatments are given in Table XV.

(*A*) *Effect of varying plot treatments on soil erosion*

When the quantities of soil carried by run-off water from the eight plots under different treatments are considered, as shown in the data in Table XVI, it can be seen that each plot shows a similar trend from year to year. Thus, plot 1, where the natural vegetation of grasses and weeds were preserved, showed the smallest degree of soil erosion in each year. Plot 5, which received the special cultural treatment of ‘ scooping ’, stood next lowest though it lost comparatively higher quantities of silt when compared with plot 1. Plot 2, which was uncultivated but from which the weeds were removed by cutting close to the surface, stood third lowest in the total quantity of silt lost during the experimental period of five years. Plot 6, which had a mixed crop of *bajri* and *tur* every year, ranked fourth in its effect on checking soil erosion. Plot 3, which received only shallow cultivation every year and carried no crop, is next in order. Plot 8 had double the length and hence double the area as compared to the rest of the plots. But, when calculated on the basis of area, the quantity of silt removed was lower than that of plot 7 with which it is otherwise comparable. Plot 7, with thorough and intensive cultivation but with no crop, lost nearly 35 per cent more silt than plot 3 with shallow cltivation. Plot 4, with thorough and intensive cultivation and carrying a crop of *jowar* during the *rabi* season, lost the highest quantity of silt during the period of five years, probably on account of the coincidence of the interculturing operations given to the plot and the occurrence of some of the heavy rainfall showers. The surface 2-inch layer of

TABLE XV

Quantity of silt in pounds carried by run-off water from each plot

Year	Total rainfall during the year (inches)	Rainfall causing run-off (inches)	Plot 1 Retention of natural vegetation	Plot 2 Natural vegetation removed by cutting	Plot 3 Shallow cultivation by harrowing	Plot 4 Thorough and intensive cultivation by ploughing and harrowing and growing *rabi* crop of *jowar*	Plot 5 'Scooping' of the surface soil after thorough cultivation	Plot 6 Thorough cultivation by ploughing and harrowing and growing *kharif bajri* and *tur* mixture	Plot 7 Thorough and intensive cultivation by ploughing and harrowing	Plot 8 Thorough and intensive cultivation as in Plot 7 with double length
1934-35	21·15	8·11	0·73	25·61	14·28	27·83	0·20	28·66	37·02	2·29
1935-36	29·52	14·77	16·24	698·88	1,679·16	3,235·48	1,099·09	1,232·28	2,654·96	2,591·12
1936-37	15·92	5·93	2·02	30·56	81·87	120·76	9·86	230·38	493·85	63·45
1937-38	26·11	19·38	6·44	2,459·52	3,185·28	2,727·24	1,411·76	3,311·56	3,291·23	6,895·09
1938-39	37·14	22·30	4·62	572·38	503·02	933·32	379·90	394·02	845·77	1,562·57
Total .	129·84	70·49	30·05	3,786·95	5,463·61	7,044·63	2,900·81	5,196·90	7,322·83	11,114·52

the soil became loose and dry as a result of these interculturing operations and a large quantity of soil from this layer was removed with the run-off water after the heavy showers of October, November, or December.

In Table XVI, the soil erosion data for five years are given as tons of silt lost per acre. The seriousness of this problem of soil erosion is brought out very markedly by these figures. Natural vegetation appears to be the most effective means of checking soil erosion. The special treatment of 'scooping', though effective in reducing erosion, still resulted in a loss of nearly 100 times the quantity of silt lost from plot 1 with natural vegetation cover. Shallow or deep cultivation proved even more harmful and resulted in the loss of still more silt as can be seen by comparing the data of plots 2, 3 and 7. Shallow cultivation resulted in an increased loss of silt by about 40 per cent, and deeper cultivation by about 90 per cent as compared with the loss of silt from plot 2 with no cultivation. Increase in the length of the plot did not increase the extent of erosion, as may be seen by comparing the results of plots 8 and 7. In fact, there seems to be a tendency to deposition of suspended silt when the distance over which the run-off water has to travel increases. The results obtained by Duley and Ackerman [1934] on this point were not conclusive. But, in general, they found that light showers caused more erosion on shorter plots, while heavy showers caused more erosion on longer plots. Fig. 6 illustrates the comparative quantities of silt lost during the five years under different treatments.

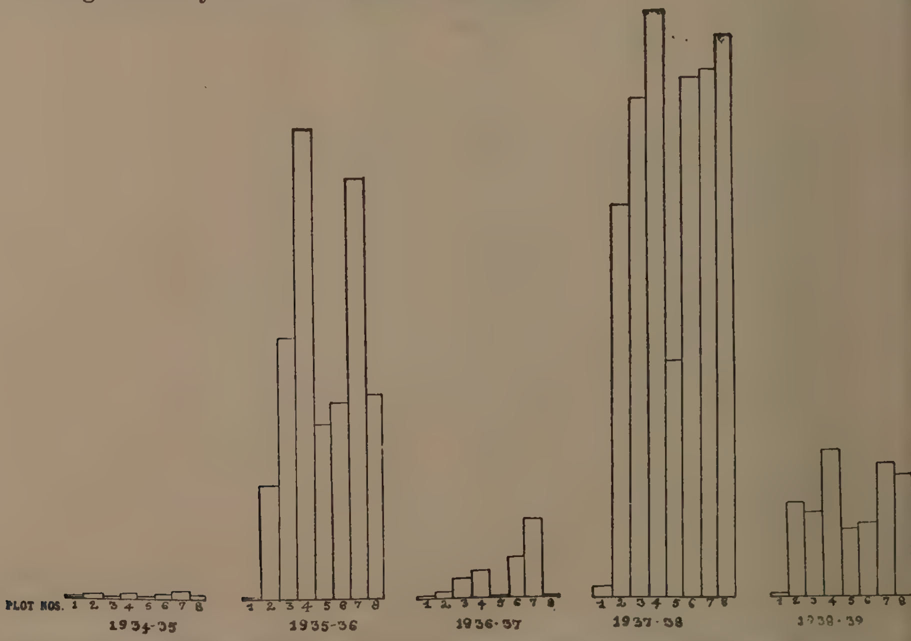

FIG. 6. Relative quantities of soil lost by erosion from plots under different treatments

[Plot 1, weeds preserved; plot 2, weeds removed; plot 3, harrowed only; plot 4, *rabi* crop of *jowar*; plot 5, scooped; plot 6, *kharif* crop of *bajri* and *tur*; plot 7, ploughed and harrowed; plot 8, ploughed and harrowed with double length]

(1 inch height of col. = 40 tons.)

TABLE XVI

Silt carried in run-off water calculated as tons per acre from plots under different treatments during five years of experiments

Year	Total rainfall during the year (inches)	Rainfall causing run-off	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
1934-35	21·15	8·11	0·026	0·916	0·510	0·993	0·007	1·023	1·322	0·576
1935-36	29·52	14·73	0·580	24·960	59·970	115·660	39·250	44·010	94·820	46·270
1936-37	15·92	5·93	0·072	1·092	2·924	4·310	0·352	8·220	17·630	1·13
1937-38	26·11	19·38	0·230	87·840	113·760	133·480	50·420	118·270	117·540	127·680
1938-39	37·14	22·30	0·165	20·442	17·960	33·330	13·570	14·070	30·210	27·900
Total during five years .	129·84	70·45	1·073	135·250	195·124	287·773	103·599	185·543	261·522	203·556
Average of five years .	25·97	14·09	0·215	27·05	39·02	57·55	20·71	37·12	52·30	40·71
Number of years required to erode 8 inches of cultivated layer of surface soil			4,146·0	32·92	22·84	15·48	43·01	24·01	17·04	21·90

On the basis of the data of five years' experimental period, the average loss of silt per year from the plot cultivated with *rabi jowar*, i.e. plot 4 was 57·55 tons per acre. This indicates that nearly ½ in. of the surface layer of soil is liable to be lost by erosion each year. If the weight of the first acre-foot surface soil is taken as three million pounds, the cultivated surface layer of 8 in. could be lost in about 15½ years if no attempt be made to check erosion by proper levelling, terracing, or bunding of the fields. This rate of erosion seems to be much greater than that found elsewhere, as in the U. S. A. It was found by Duley and Miller [1923] in their experiments in the U. S. A. that it would take 28 years to erode the cultivated surface layer of 7 in. The slope of their experimental plot was much greater, viz. 3·75 per cent, than the moderate slope of 1·18 per cent of the Sholapur experimental plots. The average rainfall at the American experimental station was also higher, viz. 35·87 in. instead of 25·96 in. at the Sholapur Experimental Station.

Accordingly tropical conditions seem to be more favourable for heavy erosion. The rate of erosion under Deccan conditions is extremely high, as may be seen by examination of the figures in the bottom line of Table XVI. The surface 8-in. layer is taken as the cultivated layer of the soil and is known to weigh about 2 million pounds per acre. From the average quantity of soil lost per year under each plot treatment, the number of years required to erode completely the cultivable layer of the surface soil has been calculated. As already pointed out, plot 4, which represents the normal cultivation of *rabi jowar* followed by a few good cultivators in this tract, shows that the surface layer is liable to be lost in an extraordinarily short period. Other methods of cultivation tried in these experiments also indicate similar high rates of erosion, requiring only 17-43 years for the removal of the cutivated layer of the surface soil. The only effective treatment for checking soil erosion was the preservation of the natural vegetation on the surface soil as represented by the treatment in plot 1.

(*B*) *Relationship between total annual rainfall and soil erosion*

The total annual rainfall during the five years during which the experimental work has been in progress has varied from 15·92 to 37·14 inches, while the total rainfall causing run-off and producing soil erosion has varied from 8·39 to 22·30 in. in the five years. It has been already shown that the total run-off is not always proportionate to the total rainfall of the year. The intensity of the showers and the moisture-status of the soil have more influence on the extent of run-off than the total rainfall. The same finding holds good in the case of soil erosion. The year 1936-37, which recorded the lowest rainfall (Tables XV and XVI), was not the year of the lowest soil erosion. In the same way the year 1938-39 with the highest total rainfall was not the year of the highest soil erosion. The year 1937-38 with only an average annual rainfall had the highest number of rainfalls causing run-off and erosion. This year, therefore, proved most damaging in that it gave the highest erosion.

(*C*) *Effect of the intensity of showers on soil erosion*

Out of the total amount of soil lost during each year by erosion, the greater proportion was lost during one to three intensive rainfalls only. The

term 'intensive' implies either a high total rainfall or rainfall that is received as stormy showers, within a short period of time, e.g. 1-2 hours. Thus, in the first year only one rainfall on 7 September amounting to 2·67 in., received overnight, resulted in the loss of 89 per cent of the total silt removed during the year from plot 4 (Appendix I-*b*). In the second year, out of nine rainfalls causing erosion, two only accounted for 90 per cent of the total soil lost by erosion in that year. In the third year, two rainfalls out of five were responsible for the greater part of soil loss. In the fourth year, out of 20 rainfalls, three intensive falls only resulted in the loss of nearly 80-90 per cent of the total silt lost during the whole year. In the fifth year again, only two rainfalls out of 15 falls resulting in erosion caused the greater proportion of soil loss.

Thus, out of the large number of rainfalls (55) causing erosion (Table XI) during the five years, only 10 rainfalls could be termed intensive and these resulted in the loss of 80-90 per cent of the total soil lost from the seven plots under different treatments, during the experimental period of five years, as shown in Table XVII. In this respect, the data regarding run-off of rain water alone are somewhat different. In the case of run-offs, a greater number of total rainfalls is required to make up 80-90 per cent of the total loss of rain water. This indicates that the intensity of a shower has a greater influence on erosion than on run-off.

TABLE XVII

High proportion of silt lost in five years by ten intensive rainfalls

Plot No.	Treatment	Total pounds of soil lost during the 5 years	Total pounds of soil lost during the 10 intensive rainfalls	Percentage of total soil lost by ten rainfalls
1	Retention of vegetation	30·05	16·08	53·52
2	Removal of vegetation	3787·01	3437·61	91·07
3	Shallow cultivation	5463·61	5055·45	92·55
4	Cultivation of *rabi jowar*	8054·83	7367·47	91·47
5	'Scooping'	2900·72	2601·96	89·71
6	Cultivation of *kharif bajri* and *tur*	5196·90	4206·98	80·93
7	Thorough and intensive cultivation	7422·83	6547·24	88·22
8	Thorough cultivation and double length	11144·52	10234·37	91·83

(*D*) *Moisture-status of the soil previous to soil erosion, and its effect on soil erosion*

As the type of soil erosion considered here is dependent upon the run-off of rain water, all the factors that affect rainfall run-off also affect soil erosion. The moisture-status of the soil, previous to rainfalls causing run-off of rain-water has been shown to influence the quantity of rain water lost by such run-off. A similar influence of this factor on soil erosion can be seen from the detailed data of soil lost by erosion given in Appendix I-*b*. Comparatively greater losses of soil take place from erosion after the surface soil attains moisture-saturation which does not usually happen before August or September.

(*E*) *Relative proportion of water and silt lost by run-off and erosion*

It will be interesting to examine whether any relationship exists between the quantity of water lost by a run-off and the amount of silt carried away by such run-off water. The comparative quantities of water and silt lost in pounds from each plot during the five years of experiments are given in Table XVIII. In the last line of this table, the ratio of the total water lost to the total soil removed is shown for the whole period of five years. It may be said in general, that the greater the amount of water lost, the greater is the amount of silt removed. But the ratio of losses of water to losses of soil differs widely, e.g. from 7·96 to 520·8, according to the varied treatments given to the plots. The plot with vegetation cover gives the widest ratio of 520·8 and differs entirely in this respect from the other treatments. The remaining seven treatments show a ratio ranging from 7·96 to 18·07. This would indicate that the capacity of run-off water to remove soil under the experimental conditions at Sholapur is very high when compared with the results obtained in similar experiments conducted in the U. S. A. The curve showing the relation of water lost to soil eroded shows a general relationship between run-off and erosion under different treatments (Fig. 7). Under tropical and arid conditions, the rate of soil erosion appears to be very high. It may be pointed out that the soil type in the present experiment cannot be considered as erodible according to Middleton as it belongs to the heavy clay type but the results obtained in the experiments at Sholapur agree with the views of Bennett who considers sticky soils with high swelling and shrinkage capacity as very erodible.

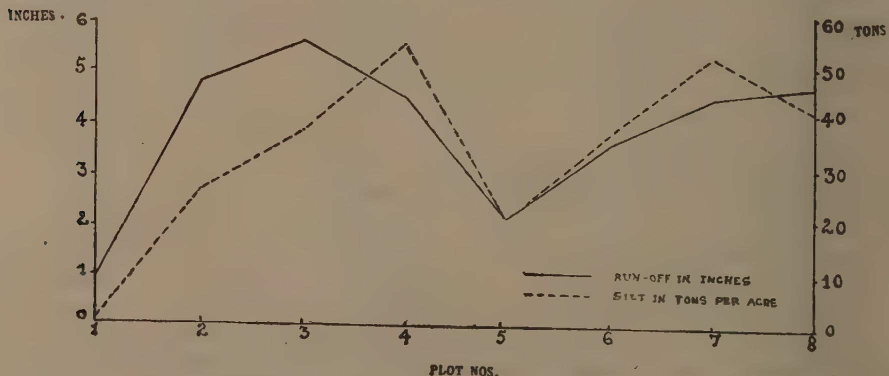

Fig. 7. Relative proportion of water and silt lost by run-off and erosion under different treatments

[Plot 1, weeds preserved; plot 2, weeds removed; plot 3, harrowed only; plot 4, *rabi* crop of *jowar*; plot 5, scooped; plot 6, *kharif* crop of *bajri* and *tur*; plot 7, ploughed and harrowed; plot 8, ploughed and harrowed with double length]

TABLE XVIII

Comparative quantities of water lost by run-off and silt carried in pounds per acre

Year	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt	Water	Silt
1934-35	588	0·7	3,836	26	3,472	14	56	28	1,904	0·2	1,904	29	3,976	37	6,776	32
1935-36	11,256	16·3	16,240	699	15,960	1,679	15,540	3,235	10,724	1,099	12,936	1,232	14,056	2,655	29,736	2,591
1936-37	196	2·0	2,968	31	6,216	82	5,292	121	532	9·9	4,424	230	5,402	494	12,264	63
1937-38	1,820	6·4	17,808	960	23,408	3,185	20,916	3,737	12,096	1,412	19,572	3,312	19,992	3,291	43,344	6,895
1938-39	1,792	4·6	27,552	572	26,628	503	19,373	933	5,628	380	1,234	846	17,948	845	35,280	1,563
Total for five years, (From 1 June 1934 to 31 May 1939)	15,652	30·0	68,404	4,288	75,684	5,463	61,177	8,054	30,884	2,901	40,070	5,649	61,374	7,322	1,27,400	11,144
Pounds of water required to carry 1 lb. of silt in the run-off water	520·8		18·06		13·86		7·96		10·01		9·85		8·27		11·44	

Although the ratios of soil removed to rainfall run-off for the whole period of five years under seven different treatments show a limited variation, the actual day-to-day ratios have been found to show extraordinary variation. A litre of water could carry silt in suspension varying from less than 1 gm. to more than 400 gm. on different days, depending upon various factors, such as the total quantity of rainfall, intensity of showers, and the moisture-status of the soil previous to run-off.

(*F*) *Effects of soil erosion*

(*a*) *Increase in the slope of land*

Before the commencement of the experiments at Sholapur in 1934, accurate levels of the experimental plots were determined by a dumpy level along three lines in each plot at every 5 ft. distance. From the difference between the average levels at the top and at the bottom, the percentage slope of each plot was determined. The average slope for all the plots was 1·18 per cent or a fall of 1 in 85, in 1934. At the end of the period of five years, levels were again determined by the same method in all plots. The average slope for all plots was found to have increased to 1·68 per cent or a fall of 1 in 60, in 1939.

Thus, the accumulated loss of soil from the plots due to erosion during a period of five years had resulted in increasing appreciably the original slope of the plots. Such an increase in gradient is likely to accelerate the rate of run-off and also of erosion. This change in level is illustrated in the vertical section of plot 4, along the length, in Fig. 8.

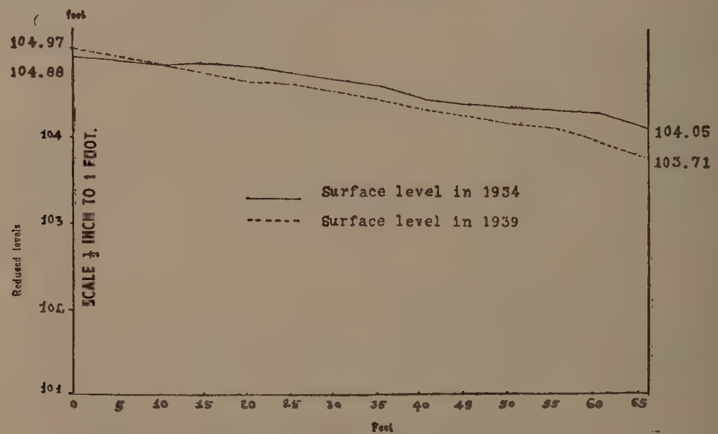

FIG. 8. Change in gradient of plot 4 by soil erosion

(*b*) *Loss of fertility elements*

The soil lost by erosion after each rain-fall resulting in run-off of rain water from the eight different plots was collected for a period of three years, viz. 1934-35, 1935-36 and 1937-38. A composite sample was prepared each year for each plot by taking a proportionate quantity from each bulk of eroded material and these samples were analysed for total nitrogen.

TABLE XIX

Percentage of nitrogen in silt obtained in run-off waters and pounds of nitrogen lost per acre from different treatments

Plot No.	1934-35		1935-36		1937-38		Average for 3 years	
	Percentage of N in silt	Pounds of N lost per acre	Percentage of N in silt	Pounds of N lost per acre	Percentage of N in silt	Pounds of N lost per acre	Percentage of N in silt	Pounds of N lost per acre
1. Retention of vegetation	0·133	0·07	0·109	1·41	...	...	0·082	0·74
2. Removal of vegetation	0·059	1·21	0·047	26·27	0·051	107·51	0·052	44·99
3. Shallow cultivation	0·069	0·79	0·050	67·26	0·056	142·70	0·058	70·21
4. Cultivation of *rabi jowar*	0·052	1·15	0·049	126·95	0·055	184·47	0·052	104·19
5. 'Scooping'	0·068	0·01	0·042	36·92	0·052	58·73	0·054	32·88
6. Cultivation of a *kharif crop* of *bajri* and *tur*	0·046	1·05	0·050	49·28	0·062	175·98	0·053	75·44
7. Thorough cultivation	0·052	1·54	0·046	97·70	0·059	155·34	0·052	84·86
8. Thorough cultivation with double length	0·087	1·15	0·056	58·04	0·070	200·20	0·071	86·46

TABLE XX

Chemical analysis of silt lost from surface run-off plots during 1935-36

(Expressed on per cent dry matter)

Plot No.	Loss on ignition	Sand	Fe_2O_3	Al_2O_3 and TiO_2	CaO	MgO	K_2O	P_2O_5	Nitrogen	Stone per cent on original
1. Retention of vegetation	10·51	55·18	10·10	12·95	1·80	1·28	0·59	0·06	0·109	6·65
2. Removal of vegetation	7·35	55·47	10·73	11·10	4·69	1·38	0·47	0·05	0·047	23·42
3. Shallow cultivation	7·23	55·76	10·88	12·60	3·43	1·58	0·48	0·06	0·050	12·53
4. Cultivation of *rabi jowar*	7·30	54·59	10·66	13·42	3·28	1·64	0·49	0·05	0·049	15·09
5. 'Scooping'	7·71	56·46	11·21	12·07	3·59	1·54	0·53	0·05	0·042	7·90
6. Cultivation of *kharif bajri* and *tur*	6·83	56·66	11·90	12·57	2·72	1·33	0·51	0·06	0·050	7·38
7. Thorough cultivation	7·73	56·46	11·53	12·12	2·80	1·24	0·57	0·06	0·046	11·16
8. Thorough cultivation with double length	8·02	59·53	11·69	12·55	1·61	1·32	0·50	0·06	0·056	3·43

The percentage of nitrogen present in the eroded soils obtained each year was distinctly higher than that found in the original soil which was only 0·039 per cent. The presence of vegetation on plot 1 naturally increased the nitrogen content of the soil from that plot. Table XIX shows the percentage nitrogen in soil and estimated quantities of nitrogen lost per acre under different experimental treatments during the three years. It may be seen that the quantity of nitrogen lost has varied according to the quantity of silt carried off by the run-off water from the plots under different treatments.

The average annual loss of nitrogen per acre during the three years was found to be very high from all cultivated plots, whether with or without crops, although that loss varied considerably from year to year. Only in the case of the plot with natural vegetation-cover, was the loss very low due to low loss of soil. The average loss of nitrogen per year is equivalent to nitrogen removed by 8 or 10 crops of *jowar* or *bajri* when cultivated on this type of soil in this tract. These losses are higher than the results of similar estimation made by the American workers [Miller and Krusekopf, 1932].

Complete chemical analysis of the eroded soils from different plots was made in the year 1935-36, by the method of hydrochloric acid digestion. The results of these analyses indicated that soils removed were richer in important fertility constituents than the original soil (Table XX).

XV SUMMARY OF THE EXPERIMENTS AT SHOLAPUR

RAINFALL RUN-OFF

1. Experiments conducted at Sholapur for a period of five years from 1934-35 to 1938-39, to determine the loss of rain water by surface run-off, are described.

2. The soil type upon which these experiments were conducted belongs to the Chernozem group derived from the Deccan trap. It has a high clay content and is rich in potash and lime but comparatively poor in nitrogen and phosphoric acid.

3. Eight unit plots were laid down under the following treatments* respectively :—

(1) Preservation of natural vegetation—no crop.
(2) Natural vegetation above soil surface level removed by cutting—no crop.
(3) Shallow cultivation by harrowing—no crop.
(4) Thorough and intensive cultivation with subsequent cultivation of *rabi jowar* crop.
(5) Special cultural treatment with a 'scooper'—no crop.
(6) Thorough and intensive cultivation followed by a mixed crop of *bajri* and *tur*.
(7) Thorough and intensive cultivation only—no crop.
(8) Thorough and intensive cultivation on a plot length double that of plots 1 to 7—no crop.

*It will be noted that crop cultivation was carried out on plots 4 and 9 only. Intensive cultivation implies deep ploughing in the hot weather season followed by several harrowings during the monsoon period and several interculturings during the normal period of crop growth. Ploughing was done across the slope of the plots.

4. The shape of the plots was a rectangle having the dimensions 66 ft. length × 8·25 ft. width in the first seven plots and 132 ft. length × 8·25 ft. width in the eighth, with an average one way slope of 1·18 per cent along the length of the plots.

5. The average annual rainfall during the experimental period of five years corresponded closely with the average annual precipitation in the tract during the past 25 years. The monthly distribution of rainfall, however, showed some deviation from the average. The average number of rainy days* per year during the experimental period of five years and the past 25-years period was also similar.

6. The annual number of rainfalls causing run-off of rain water during the five-year period varied from 5 to 20, the annual average for the whole period being 11.

7. These run-offs of rain water were mostly restricted to the period from June to October. The month of September recorded the highest number. The average annual loss of water by run-off varied from 1·12 in. to 5·40 in. under the different treatments under experiment.

8. All the rainfalls received during the experimental period of five years have been grouped into four classes according to their intensities, i.e. according to the quantity of rainfall received during a day, i.e. 24 hours. It is found that all rainfalls exceeding 2 in. during a day resulted in run-off of rain water. There were nine such rainfalls during the experimental period of five years. The total number of rainfalls in class 2, i.e. rainfalls varying from 1 in. to 2 in. during a day, was 25 and, of these, 20 rainfalls or 80 per cent of the total caused run-off of rain water. There were 40 rainfalls varying from ½ in. to 1 in. received in a day in class 3. Of these, 14 rainfalls or 35 per cent caused rainfall run-off. The last class consisted of 144 rainfalls of less than ½ in. recorded during a day. Of these, only 12 rainfalls or 8 per cent of the total of this class resulted in run-off of rain water.

9. The previous moisture-status of the soil influenced the occurrence and extent of run-off very greatly.

10. The number of rainfall run-offs appeared to depend more on the number of heavy showers received during the year rather than on the total annual rainfall. Rainfalls exceeding 1 in. received during a day, i.e. 24 hours, are reckoned as heavy showers.

11. The treatments which appear to have the greatest effect in checking or reducing the run-off of rain water are :—

(1) the preservation of the natural vegetation,

(2) the special treatment of 'scooping',

(3) the presence of a mixed crop of *bajri* and *tur* after intensive cultivation.

12. Thorough and intensive cultivation alone showed a more restricting influence on the number of rainfall run-offs and on the quantity of water lost by such run-offs, when compared with shallow cultivation or no cultivation.

* A 'rainy' day indicates a day of 24 hours upon which 10 cents or more of rainfall were received.

13. The doubling of the length of the plot, or the growing of a *rabi* crop of *jowar*, showed no noticeable difference in influencing the number of rainfall run-offs or the quantity of water lost by such run-offs.

14. Appreciable quantities of soluble salts are removed from soils in rainfall run-off, lime forming a considerable proportion of such losses. The loss of nitrogen and phosphoric acid in solution was however found to be very small.

Soil erosion

I. The extent of soil erosion was determined annually by measuring the quantities of soil carried away by run-off of rain water from the same eight unit experimental plots under different treatments (para. 3 above) upon which the run-offs of rain water were determined during the five years of the experiments.

II. The same eight different plot treatments as mentioned in para. 3 above were compared to see their comparative effect on soil erosion.

III. The annual average loss of soil by erosion varied from 0·215 tons per acre in plot 1, i.e. the plot with natural vegetation preserved, to 57·55 tons per acre in plot 4, i.e. the plot with the *rabi* crop of *jowar* following intensive hot weather cultivation. The special treatment of 'scooping', i.e. plot 5, gave an average loss of 20·71 tons per acre, showing some checking effect of this treatment on soil erosion. Plot 2 with vegetation removed and without cultivation showed less erosion, viz. 27·05 tons per acre, than plots with shallow and intensive cultivation, i.e. plots 3 and 7 respectively, which showed 39·02 and 52·30 tons per acre respectively. The standing crop of *bajri* and *tur* mixture after intensive hot weather cultivation, i.e. plot 6, had some effect in reducing soil erosion, this plot giving an average loss of 37·12 tons per acre. Increase of the length of the plot, i.e. plot 8, showed an average loss of 40·71 tons per acre, and the tendency to the deposition of silt along the plot surface reducing the erosion to some extent.

IV. Except on the plot with natural vegetation preserved, i.e. plot 1, the average quantity of run-off water required to remove 1 lb. of soil showed a variation of from 0·796 to 1·806 gallons under different treatments. These figures indicate an extremely high rate of erosion under the Deccan conditions.

V. The average number of occasions upon which soil erosion was found to take place was 11 per annum. Of these, only two per year, on an average, are responsible for causing 80-90 per cent of the total loss of silt by erosion during the year. The rainfall on these two occasions was very heavy and intensive, usually more than 2 in. received in a few hours on an already saturated soil surface.

VI. As a result of soil erosion during five years, the original slope of the plots was found to have appreciably increased.

VII. The soil removed by rainfall erosion is richer in all plant food ingredients than the original soil. The average quantity of nitrogen lost in such eroded soil in a year is equivalent to that removed by 8-10 *jowar* or *bajri* crops.

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APPENDIX I

(a) Rainfall received on rainy days classified according to intensity, during the experime period of five years

Class	Rainfall in inches*	June	July	August	September	October	November	December	January	February	March	April	Ma
						(1934-35)							
1	0—¼ . .	0·10	0·17	0·17	0·11	0·10	0·18	...	0·19	...	...	0·23	0·
		0·25	0·10	0·39	0·35	0·13	0·20	...	...	...	...	0·12	.
		0·11	0·17	0·31	*0·17*	...	...	...	...	...	...	...	.
			0·25	0·12	0·29								
			0·10	*0·36*	0·18								
			0·25	0·24	0·30								

APPENDIX I—*contd.*

Class	Rainfall in inches	June	July	August	September	October	November	December	January	February	March	April	May
	(1934-35)—*contd.*												
			0·49		0·20								
			0·40		0·14								
			0·31		0·14								
			0·13										
2	½—1 . . .		0·93	0·95	0·75								
			0·50										
3	1—2 . . .			1·13	*1·22*		1·24						
				1·52									
4	Above 2 . .		*2·17*		*2·67*								
	(1935-36)												
1	0—½ . . .	0·17	0·16	0·38	0·24	0·15	...	0·43	...	0·47	0·36	...	...
		0·20	0·12	0·14	0·41	0·43				0·26			
		0·16	0·13	*0·48*	0·29	0·23							
		0·34	0·12	0·47	0·25	0·42							
		0·13		0·23		0·13							
		0·20											
		0·26											
2	½—1 . . .	0·75											
		0·54	*0·78*	0·50	0·96	0·51						0·65	0·70
		0·69	0·65	*0·54*	0·99								
3	1—2 . . .			*1·57*									
				1·03									
				1·86									
4	Above 2 . .			*3·52*		*4·30*							
	(1936-37)												
1	0—½ . . .	0·18	0·16	0·25	0·14	0·37				0·21	0·49	0·22	
			0·25	0·35	0·47						0·20	0·41	
			0·10	0·16	*0·42*								
			0·10		0·13								
2	½—1 . . .	0·84	*0·85*				*0·90*					0·56	
		0·70					0·69						
		0·56											
3	1—2 . . .				*1·73*							1·03	
4	Above 2 . .						*2·03*						

APPENDIX I—*contd.*

Class	Rainfall in inches	June	July	August	September	October	November	December	January	February	March	April	May
(1937-38)													
1	0—½ . . .		0·16	0·15	0·30	0·39		*0·39*				0·11	0·31
			0·27	0·14	*0·38*			*0·34*					0·10
			0·47		0·32								
			0·33		*0·44*								
			0·42		0·28								
			0·17		0·12								
			0·14		0·26								
			0·24										
			0·21										
			0·22										
			0·14										
2	½—1 . . .	*0·98*	*0·63*	*0·54*		*0·67*					0·81		
		0·80		0·52		*0·62*							
3	1—2 . . .				*1·30*	*1·97*		*1·35*			*1·40*		
					1·15	*1·44*							
4	Above 2 . .				*2·13*								
					2·05								
(1938-39)													
1	0—½ . . .	0·34	0·25	0·16	0·31	0·23						0·25	
		0·10	0·44	0·19	*0·26*							0·18	
		0·31	0·10	0·28									
		0·15	0·11	0·10									
		0·30	0·30	0·10									
		0·18	0·42	0·16									
		0·10	0·27	0·24									
		0·16	*0·34*	0·10									
			0·15	0·26									
			0·33										
			0·30										
			0·11										
			0·41										
			0·10										
2	½—1. . .	*0·94*	*0·96*	0·65	0·66	0·75							
		0·60		0·59	0·79								
					0·56								
3	1—2 . . .	*1·90*	*1·72*	1·60	*1·14*								
		1·50	*1·78*		*1·76*								
		1·78	1·13		*1·14*								
4	Above 2 . .		*2·32*		*4·06*								

* The figures in *italics* indicate the rainfall that caused run-off of rain water and soil erosion.

APPENDIX I—*contd.*

(b) Loss of rain water by run-off in inches and loss of soil by erosion in pounds per acre on each day of run-off during the experimental period of five years

(1934-35)

Plot	Treatment	Dates	30-7-34	2-8-34	26-8-34	4-9-34	7-9-34	8-9-34
		Rainfall	2·17	1·52	0·36	1·22	2·67	0·17
1	Retention of vegetation	Run-off water	0·006	...	0·006	0·004	0·190	0·003
		Silt lost	1·15	...	7·69	0·70	48·50	0·83
2	Removal of vegetation	Run-off water	0·037	...	0·024	0·148	1·105	0·061
		Silt lost	13·69	...	107·72	239·55	1,648·03	45·29
3	Shallow cultivation	Run-off water	0·019	...	0·023	0·097	1·040	0·063
		Silt lost	3·54	...	47·37	59·62	975·86	56·48
4	Cultivation of *rabi jowar*	Run-off water	0·018	...	0·025	0·099	0·896	0·053
		Silt lost	6·39	...	12·60	160·81	1,979·25	67·90
5	'Scooping'	Run-off water	...	...	0·003	0·003	0·015	...
		Silt lost	...	...	8·38	1·73	6·17	...
6	Cultivation of a *kharif* crop of *bajri* and *tur*	Run-off water	0·037	0·032	0·011	0·053	0·505	0·043
		Silt lost	24·29	13·82	125·03	185·08	1,883·97	61·17
7	Thorough cultivation	Run-off water	0·123	0·021	0·023	0·145	1·067	0·042
		Silt lost	126·09	4·66	212·31	559·14	2,004·31	55·14
8	Thorough cultivation with double length	Run-off water	0·046	...	0·006	0·108	1·000	0·053
		Silt lost	6·05	...	44·45	78·74	1,130·66	31·78

APPENDIX 1—*contd.*

(1935-36)

Plot	Treatment	Dates	26-6-35	5-7-35	24-8-35	25-8-35	27-8-35	28-8-35	29-8-35	30-8-35*	24-10-35*
		Rain-fall	0·69	0·78	3·52	0·48	1·57	1·03	0·54	1·86	4·30
1	Retention of vegetation	Run-off water	...	...	1·13	...	0·35	0·32	0·16	1·02	1·03
		Silt lost	...	...	419·0	...	145·4	201·4	92·0	7·5	453·9
2	Removal of vegetation	Run-off water	0·019	0·011	1·54	0·003	0·67	0·56	0·24	1·29	1·46
		Silt lost	9·3	5·80	3,697·0	1·4	898·0	1,585·0	1,461·0	31,940·0	16,365·0
3	Shallow cultivation	Run-off water	0·051	0·011	1·52	0·007	0·73	0·59	0·22	1·17	1·39
		Silt lost	40·4	3·9	5,217·0	2·6	971·6	1,635·5	878·0	85,570·0	40,000·0
4	Cultivation of *rabi jowar*	Run-off water	0·011	...	1·51	0·024	0·76	0·55	0·22	1·18	1·29
		Silt lost	2·7	...	11,140·0	18·7	4,325·0	6,800·0	2,544·0	137,800·0	97,160·0
5	'Scooping'	Run-off water	...	...	1·51	...	0·19	0·33	0·03	1·02	0·73
		Silt lost	...	...	5,966·0	...	464·7	1,165·0	336·5	43,120·0	36,870·0
6	Cultivation of *kharif* crop of *bajri* and *tur*	Run-off water	...	...	1·46	...	0·51	0·50	0·16	1·14	0·83
		Silt lost	...	...	38,635·0	...	1,726·6	14,890·0	846·1	36,100·0	6,461·0
7	Thorough cultivation	Run-off water	...	...	1·37	0·006	0·63	0·38	0·22	1·25	1·15
		Silt lost	...	...	21,460·0	3·8	4,689·0	6,586·0	1,735·0	53,510·0	124,400·0
8	Thorough cultivation with double length	Run-off water	...	...	1·51	...	0·51	0·29	0·20	1·24	1·54
		Silt lost	...	...	11,570·0	...	626·4	2,264·0	729·3	48,770·0	39,680·0

* Shows rainfall of great intensity mentioned in Table XVII

APPENDIX I—*contd.*

(1936-37)

Plot	Treatment	Date	23-7-36	26-9-36	28-9-36	13-11-36*	14-11-36*
		Rainfall	0·85	1·73	0·42	2·03	0·90
1	Retention of vegetation	Run-off water	...	0·05	...	0·02	...
		Silt lost	...	92·6	...	69·49	...
2	Removal of vegetation	Run-off water	0·09	0·48	0·04	0·27	0·18
		Silt lost	101·6	775·3	65·0	592·6	911·0
3	Shallow cultivation	Run-off water	0·04	0·70	0·06	1·02	0·40
		Silt lost	57·9	909·5	84·5	2,381·0	3,775·0
4	Cultivation of *rabi jowar*	Run-off water	...	0·69	0·01	0·82	0·37
		Silt lost	...	1,051·0	22·3	3,514·0	5,174·0
5	'Scooping'	Run-off water	...	0·09	...	0·10	0·005
		Silt lost	...	433·0	...	291·6	64·59
6	Cultivation of *kharif* crop of *bajri* and *tur*	Run-off water	...	0·48	...	0·76	0·34
		Silt lost	...	596·9	...	11,690·0	6,144·0
7	Thorough cultivation	Run-off water	...	0·68	0·03	0·83	0·39
		Silt lost	...	969·8	47·2	37,190·0	1,301·9
8	Thorough cultivation with double length	Run-off water	...	0·78	0·02	0·0[illegible]	0·49
		Silt lost	...	688·0	25·7	1,151·0	673·3

* Shows rainfall of great intensity mentioned in Table XVII

APPEN

(1937-

Plot	Treatment	Date .	17-6-37	19-6-37	6-7-37	10-7-37 / 11-7-37	5-8-37	2-9-37	3-9-37
		Rainfall .	0·98	0·80	0·47	0·96	0·54	1·30	0·38
1	Retention of vegetation	Run-off water	...	...	...	...	...	...	...
		Silt lost .	...	...	...	...	...	...	...
2	Removal of vegetation	Run-off water	...	0·22	0·07	0·13	0·03	0·28	...
		Silt lost .	...	323·4	278·3	198·1	64·8	203·0	...
3	Shallow cultivation	Run-off water	0·26	0·43	0·08	0·15	0·08	0·61	Trace
		Silt lost .	371·5	902·4	362·1	267·7	121·5	388·8	14·56
4	Cultivation of *rabi jowar*	Run-off water	0·21	0·42	Trace	0·08	...	0·38	...
		Silt lost .	373·0	1,614·0	87·32	124·6	...	280·0	...
5	(Scooping) .	Run-off water	0·19	0·37	...	...	...	0·24	...
		Silt lost .	358·8	1,788·0	...	...	...	232·7	...
6	Cultivation of *khari* crop of *bajri* and *tur*	Run-off water	0·18	0·40	Trace	0·07	...	0·45	...
		Silt lost .	287·1	1,806·0	85·6	146·5	...	220·2	...
7	Thorough cultivation	Run-off water	0·03	0·39	Trace	0·08	...	0·41	...
		Silt lost .	121·1	1,381·0	79·40	150·3	...	497·2	...
8	Thorough cultivation with double length	Run-off water	0·05	0·36	...	0·06	...	0·50	...
		Silt lost .	103·7	438·8	...	91·4	...	336·9	...

(1938

Plot	Treatment	Date .	7-6-38 / 8-6-38	19-6-38	20-6-38 / 21-6-38	22-6-38
		Rain-fall	2·0	1·50	2·72	0·60
1	Retention of vegetation . .	Run-off water . .	...	...	0·15	...
		Silt lost . . .	...	...	66·9	...
2	Removal of vegetation . .	Run-off water . .	0·38	0·56	1·59	0·15
		Silt lost . . .	229·5	1,154·0	1,986·0	88·0
3	Shallow cultivation . . .	Run-off water . .	0·28	0·57	1·55	0·16
		Silt lost . . .	173·2	865·4	2,187·0	83·8
4	Cultivation of *rabi jowar*. .	Run-off water . .	...	0·35	1·27	0·12
		Silt lost . . .	...	441·0	2,010·0	78·4
5	'Scooping'	Run-off water . .	...	...	Trace	...
		Silt lost . . .	...	...	106·2	...
6	Cultivation of *kharif* crop of *bajri* and *tur*	Run-off water . .	...	0·34	1·09	0·08
		Silt lost . . .	...	533·8	3,960·0	55·38
7	Thorough cultivation . .	Run-off water . .	...	0·41	1·28	0·011
		Silt lost . . .	...	448·8	3,359·0	67·0
8	Thorough cultivation with double length	Run-off water . .	...	0·04	1·19	0·08
		Silt lost . . .	...	90·6	660·1	46·6

DIX I—*contd.*

38)

21-9-37	22-9-37	*24-9-37	*25-9-37	2-10-37	3-10-37* 4-10-37	5-10-37	13-12-37	14-12-37	24-12-37	26-3-38
1·15	0·44	2·13	2·05	0·67	2·59	1·44	0·39	0·34	1·35	1·40
...	...	0·24	0·31	...	0·10	...	...	...	Trace	...
...	...	145·1	185·6	...	73·63	...	...	...	100·9	...
0·29	0·06	1·20	1·42	0·30	1·26	0·61	...	...	Trace	0·49
394·1	95·8	58,650·0	75,010·0	78·2	55,650·0	4,109·0	...	...	942·3	712·2
0·48	0·08	1·39	1·37	0·22	1·08	0·48	0·01	0·01	1·05	0·58
589·4	107·4	79,930·0	89,300·0	1,294·0	72,810·0	3,075·0	31·02	47·2	4,435·0	739·2
0·46	Trace	1·38	1·39	0·16	1·07	0·48	...	...	1·07	0·37
349·4	11·82	16,500·0	115,000·0	805·0	44,230·0	3,256·0	...	...	15,410·0	838·1
...	...	0·55	0·96	0·15	0·87	0·40	...	...	0·57	0·02
...	...	35,130·0	40,100·0	799·1	22,720·0	8,782·0	...	...	2,885·0	168·7
0·18	...	1·42	1·28	0·19	1·08	0·62	...	...	0·78	0·34
215·3	...	117,300·0	93,670·0	1,172·0	34,040·0	6,816·0	...	...	5,331·0	854·3
0·40	0·04	1·27	1·29	0·27	1·23	0·46	...	...	0·92	0·35
549·3	73·60	113,200·0	94,450·0	3,390·0	35,850·0	9,397·0	...	...	3,533·0	582·9
0·42	0·03	1·40	1·22	0·26	1·35	0·50	...	...	1·13	0·46
417·8	40·30	76,470·0	134,000·0	3,125·0	55,440·0	10,810·0	...	...	4,255·0	501·4

39)

*3-7-38	6-7-38	8-7-38	13-7-38	16-7-38	3-9-38	10-9-38	21-9-38	*24-9-38 25-9-38
2·32	1·72	1·73	0·34	0·96	1·14	1·76	1·14	4·32
Trace	...	...	...	...	...	...	...	0·49
47·4	...	...	...	...	...	...	...	254·6
1·59	0·48	0·36	0·02	0·24	0·48	0·96	0·49	2·74
12,310·0	799·7	626·2	42·0	360·2	792·3	1,810·0	2,019·0	23,560·0
1·40	0·47	0·31	0·01	0·20	0·43	0·89	0·49	2·75
12,640·0	11,49·0	226·8	27·8	269·3	313·4	1,521·0	3,796·0	16,990·0
1·15	0·03	Trace	...	0·06	0·31	0·60	0·42	2·61
13,650·0	44·8	10·7	...	39·4	195·2	729·5	2,446·0	54,920·0
0·02	...	...	...	...	...	0·17	0·04	1·78
130·4	...	...	...	...	...	176·7	230·4	29,730·0
0·62	0·10	0·07	...	0·08	0·11	0·13	0·04	1·75
1,916·0	120·4	91·0	...	73·3	98·9	116·1	229·2	24,340·0
0·63	0·20	0·03	...	0·07	0·31	0·64	0·38	2·35
21,330·0	189·2	29·0	...	74·8	175·1	416·5	1,090·0	40,480·0
1·16	0·13	Trace	...	0·05	0·38	0·67	0·41	2·19
2,034·0	86·7	23·3	...	9·5	216·7	523·4	753·6	58,060·0

* Shows rainfall of great intensity mentioned in Table XVII

APPENDIX I—*concld.*

(*c*) *Total soluble salts in run-off water*

(Expressed in pounds per acre)

Plot No. and treatment	1934-35	1935-36	1936-37	1937-38	1938-39	Total during 5 years 1934-35 to 1938-39	Average per annum
1. Retention of vegetation	11·18	75·09	5·57	16·45	23·32	131·61	26·32
2. Removal of vegetation	53·31	101·70	24·39	138·87	255·70	573·97	114·79
3. Shallow cultivation	43·43	124·51	36·90	174·48	297·70	677·02	135·40
4. Cultivation of *rabi jowar*	48·31	104·41	26·06	148·06	234·02	560·86	112·17
5. 'Scooping'	6·06	81·60	2·28	101·51	71·08	268·53	53·70
6. Cultivation of *kharif bajri* and *tur*	36·12	83·27	28·29	143·66	155·59	446·23	89·38
7. Thorough cultivation	37·81	93·07	30·84	143·74	175·17	490·63	98·12
8. Thorough cultivation with double length	41·68	88·48	33·22	130·55	171·54	465·27	93·05

(*d*) *Total soluble lime* (*CaO*) *in run-off waters*

(Expressed in pounds per acre)

Plot No. and treatment	1934-35	1935-36	1936-37	1937-38	1938-39	Total during 5 years 1934-35 to 1938-39	Average per annum
1. Retention of vegetation	3·18	31·83	1·31	6·58	6·95	49·85	9·97
2. Removal of vegetation	15·06	42·74	6·27	48·83	98·86	211·76	42·35
3. Shallow cultivation	15·75	51·09	10·57	71·43	101·87	250·71	50·14
4. Cultivation of *rabi jowar*	18·62	44·42	9·22	62·44	91·18	225·88	45·17
5. 'Scooping'	1·43	24·62	2·42	37·67	30·46	96·60	19·32
6. Cultivation of *kharif bajri* and *tur*	8·43	36·36	9·76	64·14	64·94	182·63	36·52
7. Thorough cultivation	7·87	37·09	9·19	57·57	74·55	186·27	37·25
8. Thorough cultivation with double length	10·31	30·24	9·45	57·36	72·63	179·99	35·99

APPENDIX II

Standard error of the two run-off plots receiving similar treatments

An attempt is made here to answer any possible objection regarding the single-plot lay-out mentioned earlier. Fortunately we have some data to throw light on the possible variation between two similar plots. Plots 4 and 7 were practically the same. Plot 4 had a *rabi* crop of *jowar* from October onwards, but most of the run-offs took place before the sowing of the crop, and therefore both the plots can be considered as comparable. The data of quantities of water lost by run-off as calculated in inches from these plots during the five years are as follows.

Inches of rainfall lost by run-off

	1934-35	1935-36	1936-37	1937-38	1938-39	Total for five years
Plot 4 . .	1·09	5·55	1·89	7·47	6·92	22·92
Plot 7 . .	1·42	5·02	1·93	7·14	6·41	21·92

The results in all the years show such a great agreement between the two plots that no objection may be raised regarding the single-plot lay-out. Further, in order to find out the probable variation in the two plots receiving exactly the same treatment, the results of run-off during five years are again compared, after omitting the run-offs obtained after sowing of the *rabi jowar* in October. The following table shows the actual figures thus obtained for the two plots for five years.

Years	Plot 4	Plot 7	Total
1934-35	1·09	1·42	2·51
1935-36	4·26	3·87	8·13
1936-37	0·70	0·71	1·41
1937-38	6·14	5·87	12·01
1938-39	6·92	6·41	13·33
Total .	20·54	19·85	40·39

Analysis of variance

Due to	Degrees of freedom	Sum of squares	Mean square	Z theo.
Treatments . . .	1	0·07	0·07	Not significant for 5 per cent
Season	4	58·36	14·59	Significant for 1 per cent
Error	4	0·22	0·055	
Total .	9	58·65	..	

The analysis of variance clearly indicates that the variation between plots is very small and is not statistically significant.

A STATISTICAL STUDY OF THE RELATION BETWEEN QUALITY AND RETURN PER ACRE IN COTTON *

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WIDESPREAD attempts are being made at present to introduce long or medium-staple varieties of cotton in the short-staple tracts of India. The incentive behind this policy is primarily the demand of mill interests for a better quality product and also the partial dwindling of the foreign market for the short-staple Indian cotton. There has, therefore, been an increasing tendency to emphasize this objective in cotton breeding. In pursuing this objective, however, the vital importance of agricultural considerations such as yield cannot be ignored. In the long run agricultural factors must have full consideration, since the establishment of a new strain, however superior in quality, depends on its capacity to increase the return per acre to the cultivator, and this point is recognized by the Indian Central Cotton Committee in its policy of financing breeding schemes. Return per acre is an integration of two components, the premium obtainable for quality and the yield of lint per acre. Both the factors must, therefore, be considered together.

Opportunity was taken to study the problem in Malwa (Central India), where side by side with the indigenous cotton (*G. arboreum* var. *neglectum* forma *bengalensis*) there exists the cultivation of Cambodia (*G. hirsutum*), a superior Upland type, introduced over 20 years back. Spinners are, therefore, familiar with it, and difficulties which sometimes arise in the valuation of new and unfamiliar cottons are absent. Mills at Indore purchase it freely at a premium over the indigenous or *desi* cotton and are insistent in their demand that its cultivation shall be extended. The Institute of Plant Industry has recently commenced the distribution of a superior *desi* strain (Malvi 9) which has become popular with the cultivators on account of its higher yield and ginning, and Indian States in Malwa are trying to multiply it as rapidly as possible. Replicated yield trials of these three types, the Upland, the Malvi local and Malvi 9, under different conditions of cultivation were specially carried out at several centres in the years 1934 and 1935, and additional comparisons in other seasons are also available. Data on spinning quality and commercial valuations of different *desi* and Upland samples grown in Malwa are available for eight years (1931-38). The material is, therefore, eminently suitable for a study of the relation between price and spinning quality and its bearing on return per acre.

The commercial valuation of a cotton represents the price that the trade is pepared to pay and this price depends not only on the quality of the cotton

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but also on extraneous factors related to market conditions, such as the demand and supply of various types. In other words, the relation between price and quality is subject to the influence of these factors and may change in different seasons. The present data, which cover a sufficiently long period, have been examined in order to discover whether the relation between price and quality has in fact altered within this period, by the differential operation of these factors, as far as Indian cottons ranging in quality from 10 to 30 counts are concerned.

Quality and price

One hundred and sixty-three samples of selected and unselected *desi* and Upland cotton and of local mixtures grown at several centres in Malwa from 1931 to 1938 have been tested at the Indian Central Cotton Committee's Technological Laboratory at Bombay. Commercial valuations and figures for spinning quality in terms of 'highest standard warp counts' [Nazir Ahmad, 1932] as reported by the Director of the Technological Laboratory are given in Tables I-IV. Commercial values are given in rupees per candy (784 lb.) 'on' or 'off' the Broach basic price on the day of valuation. This basic price is attached to all grader's reports issued by the Technological Laboratory. To allow for the effect of fluctuations in the Broach basis, the differences have been re-calculated as percentages of the Broach basis and entered in the last column of each table.

Regressions of percentage difference in price on spinning value were calculated for each season separately and also an average regression for the whole period by pooling together the necessary sums of squares and products within each season. The regression coefficients and their standard errors are given below :—

Season	1931	1932	1933	1934	1935	1936	1937	1938	Average
Regression coefficient	0·81	0 53	1·90	0·10	0·64	0·65	0·74	0·58	0·66
Standard error	0·486	0·296	0·492	0 490	0·209	0 089	0·326	0·187	0·076
P	>0·05	>0 05	<0·01	Large	0 01	<0·01	<0·05	<0 01	<0·01

The regression value in the last column means that an average premium of 0·66 per cent of the Broach basis was obtained during the period 1931-38 for each increase of one count in spinning value. The individual values have ranged from 1·90 in 1933 to 0·10 in 1934, and the question whether this variation is significant, that is, whether extraneous factors have altered the premium significantly in the different seasons, can be answered by testing the heterogeneity of the regression coefficients. The regression sums of squares ($bSxy$) each with one degree of freedom and the residual sums of squares of percentage price difference ($Res.\ Sy^2$) with their respective degrees of freedom, which are required for making this test, are as follows :—

Season	$bSxy$	$Res.\ Sy^2$	Degrees of freedom
1931	93·27	237·10	7
1932	75·73	398·63	17
1933	268·14	198·09	11
1934	0·65	81·80	5
1935	168·80	178·62	10
1936	1,244·95	842·93	36
1937	288·89	1,725·90	31
1938	249·04	769·57	30
Total .	2,389·47	4,432·64	147

The total of the second column represents the regression sum of squares with eight degrees of freedom, and this can be split up into two parts, one corresponding to the average regression with one degree of freedom which is 2,237·91, and the other to differences between individual regressions with seven degrees of freedom. The significance of each of these components can be tested against the total of the residual sums of squares of percentage price differences, which is the appropriate error for this purpose. The analysis of variance takes the following form :—

Analysis of variance for testing homogeneity of regression

Due to	Degrees of freedom	Sum of squares	Mean square
Average regression	1	2,237·91	2,237·91
Differences between regression .	7	151·56	21·65
Error	147	4,432·64	30·15

The mean squares for the last two items are nearly the same, and there is thus no evidence whatsoever that the regression of price on spinning quality differed significantly from season to season. It is clear that whatever be the extraneous factors affecting the premium paid for quality, they have not altered the rate of this premium in the different seasons and in judging the relative price obtainable for varieties differing in quality we need only consider the premium determined by the average regression. The regression

equation is, $Y = 1\cdot1936 + 0\cdot6593\ (x - 20\cdot29)$, where x is the spinning value of a sample and Y its predicted valuation in terms of percentage difference from the Broach basis.

The absence of any evidence of heterogeneity among the regression coefficients in spite of the strikingly different values for the years 1933 and 1934 might be due to these coefficients being based on only a small number of degrees of freedom and having a higher error than the remaining coefficients. It will be noted that the number of samples during the period 1931-35 was smaller than in the subsequent three years ; but average regression coefficients calculated for the two periods separately were 0·6945 and 0·6512 respectively and a test for heterogeneity of regression within each period also showed that such heterogeneity did not exist. The analysis thus confirmed the conclusions described above.

Spinning values of 20 samples of Malvi 9, 27 of Cambodia and nine of local cotton are included in Tables I-III. Mean values and standard errors calculated from these data are given below :—

Variety	Mean spinning value (highest standard warp count)	Standard error of the mean	Standard error per cent of the mean
Malvi 9	18·3	0·83	4·5
Cambodia	27·3	0·70	2·5
Local cotton	12·1	0·37	3·0

The standard errors are low and indicate that the variation in the spinning value of a variety due to seasonal and locational differences within a tract is comparatively small. By substituting the mean spinning values of the three varieties in the regression equation, the average premium obtainable for each variety during the eight-year period under discussion was estimated. Cambodia was found to secure a price 10·46 per cent higher than the local cotton and 5·94 per cent higher than Malvi 9. This premium, however, corresponds to a 125 and 50 per cent improvement in spinning quality respectively.

That the relationship between price and quality calculated from the present data restricted to Central Indian cottons is probably a general one over the usual range of Indian cottons (10-40 counts) is confirmed by an examination of data from other sources. Koshal [1936] has given spinning values and commercial valuations for 65 samples of 12 varieties of Indian cotton spread over the period from 1926 to 1934. To these may also be added nine more values belonging to the varieties Cawnpore K22, Verum 262 and

Umri-Bani within the same period [Kapadia, 1936], which are not included in Koshal's data but are relevant for the purpose of the present analysis. The regression equations for price and spinning value calculated from these samples are given below :—

(i) $Y=186\cdot0+0\cdot8259\ (x-28\cdot75)$, from 65 samples

(ii) $Y=183\cdot7+1\cdot0956\ (x-27\cdot50)$, from 74 samples

where x is the spinning value of a given sample, and Y its predicted commercial value with the Broach basis at Rs. 155 per candy.

Substituting in these equations the mean spinning values of the varieties under discussion, we find from equation (i) that Cambodia obtains a price 7·3 per cent higher than the local cotton and 4·2 per cent higher than Malvi 9, the corresponding figures from equation (ii) being 10·0 and 5·7 per cent respectively. It is interesting to note that the premium for Cambodia calculated from the second equation is almost identical with that obtained from the Central Indian data. The confirmation is striking in view of the fact that Koshal's data consisted of an entirely different set of varieties covering an earlier period of five years, and in estimating the regression seasonal differences were ignored. It may be concluded that over the range of quality of Indian cottons there is a uniform relationship between price and quality, and it was not materially affected by seasonal fluctuations in market conditions and other extraneous factors during the period from 1926 to 1938. We may, therefore, confidently use the regression values as a basis for studying the profitableness or otherwise of superior varieties to the cultivator.

Yield and return per acre

It will be seen from the previous section that the margin of profit obtainable by growing superior varieties is narrow. If superior varieties tend to give any appreciably lower yield than the locally grown cotton or to require a more costly cultivation, their advantage will rapidly disappear. On the basis of the premium available for quality, Cambodia would provide equal returns per acre with Malvi 9 and local cotton with a 9·47 and 5·61 per cent lower yield of lint respectively. If the yield of lint from Cambodia fell below this level, its cultivation would become less profitable than that of the other two varieties.

Nine replicated trials were made to test the relative yields of Cambodia, Malvi 9 and local cotton on different types of land in Malwa. In 1934-35 four trials were carried out on ordinary unirrigated (*barani*) land, and one trial on rich manured and irrigated (*adhan*) land. In 1935-36 four more trials were carried out on *adhan* land. Strictly comparable yield figures for these varieties are available from another group of four trials made on ordinary land at Indore from 1935-36 to 1939-40. All these trials consisted of six to eight randomized blocks and the plot size was 1/100 acre. Yields of *kapas* (seed-cotton), ginning percentage and calculated yields of lint per acre from these 13 trials are given in Tables V-VII.

Percentage differences in the yield of lint between Cambodia on one hand and Malvi 9 and local cotton on the other calculated from these tables are given below :—

Experiments on *barani* land				Experiments on *adhan* land			
Per cent difference from Malvi 9		Per cent difference from Local		Per cent difference from Malvi 9		Per cent difference from Local	
1934	—52·1	1934	—42·5	1934	—49·5	1934	—39·2
	—50·9		—45·6				
	—34·2		—28·6	1935	—31·6	1935	—21·9
	(—30·7)		(—70·7)		—17·2		—9·5
1935	—29·7				—9·7		+2·9
		1938	+9·2		—4·7		+110·0†
			—18·4				
1938	+48·8*	1939	—32·2				
	—13·8						
1939	—39·0						

* Stand of Malvi 9 was very poor.
† Local seed was badly ginned and did not germinate well.

Figures in brackets are based on yields of seed-cotton, because ginning percentages were not estimated in this trial. Differences in the yield of lint would, however, be of the same order, as these varieties do not differ appreciably in their ginning percentages.

Referring to the percentage yield disadvantages at which Cambodia gives returns equal to those of the other two varieties, it is obvious that the yield of Cambodia is so much below this limit that its cultivation would be distinctly less profitable than that of the two *desi* varieties on *barani* land. Even on *adhan* land, for which Cambodia was considered specially suitable, the position is not more hopeful. Unless a strain capable of giving a considerably higher yield is evolved, Cambodia cannot be recommended to the cultivators in Malwa.

Discussion

The conclusion that the superior quality Cambodia is less profitable to the grower in Malwa than the inferior indigenous types is based on the price-quality relationship obtaining during the eight-year period 1931-38, to which a further five years from 1926 may be added in view of the confirmatory evidence from Koshal's data. It is difficult to predict the future trend of prices and while the present relationship between price and quality may change,

it is inconceivable that the change would be so drastic that Cambodia would give at least the same return as the two indigenous types if not more. It is obvious that only very small sacrifices in yield can be permitted if the return per acre from a variety of superior quality is to equal that of the variety it is designed to replace.

The present conclusions with regard to Central Indian cottons are of a much wider application. Instances can be quoted from other parts of the world where a similar situation exists between superior quality varieties and inferior but better yielding or better ginning varieties. I am indebted to Mr J. B. Hutchinson for the following data concerning the Bourbon and Barbadense constituents of the Marie Galante cotton of Carriacou, West Indies. At present, the two are grown mixed in all proportions in the fields, but spinning tests have shown that both are good marketable cottons of their own particular types if sold pure. Bourbon spins very much better than the Barbadense, the former being estimated to spin 35 counts as against only 14's of the latter. (These are Shirley Institute Highest Standard Counts. On the Bombay Technological Laboratory standards, the highest standard warp counts would be higher). The commercial valuation of Bourbon is 5·69*d* per pound of lint or 100 points ' on ' Middling American and of the Barbadense, 4·94*d* or 25 points ' on '. Proper yield trials for these varieties have not been made, but their ginning percentages are 22·2 for Bourbon and 27·9 for Barbadense, and if the lint value of 100 pounds of seed-cotton is worked out, it appears that Barbadense is worth 138*d* per 100 pounds of seed-cotton as against only 126*d* for the Bourbon. It is clear that even if these two varieties do not differ in the yield of seed-cotton, the inferior Barbadense is more profitable to the cultivator than Bourbon. The premium obtainable for the superior quality of Bourbon is too small to offset the disadvantage of a lower ginning percentage.

Before closing this discussion reference should be made to an investigation on this problem by Kapadia [1936] and its criticism by Mahalanobis [1936] and Koshal [1936]. From an examination of technological reports of Indian cottons, Kapadia concluded that improvement in quality progressively reduces the money return per acre. He arrived at this conclusion by comparing the high yielding but poor quality cottons of Northern India and Gujerat with the low yielding but better quality cottons of the South and omitting from consideration superior varieties like the Punjab and Cawnpore Americans from high-yielding tracts. Mahalanobis after correcting this omission came to the slightly different conclusion that when spinning value goes beyond 38, the return per acre increases. Koshal analysed data for 65 samples covering 12 varieties, for which individual yield figures were readily available. He found that there is no relationship between spinning value and the return per acre. It should be noted, however, that Koshal could not include the comparatively inferior but high-yielding varieties like Cawnpore K22 and Verum 262 in his analysis, presumably for want of proper yield data, but even so, the absence of any significant correlation between quality and return per acre in his material is chiefly due to a significant negative correlation (—0·26) between spinning value and yield of lint per acre being counterbalanced by a significant positive correlation (+0·29) between spinning value and commercial valuation.

From the agricultural point of view, the relative returns per acre of a series of varieties of different spinning qualities are of no value, unless they have been obtained from crops grown on the same land. The comparison made by Kapadia, Mahalanobis and Koshal are not relevant to the practical problem, in that they all deal with varieties grown under entirely different conditions in tracts of widely different yield potentialities. In the present investigation, exactly opposite—and equally irrelevant—results would be obtained by comparing Cambodia cotton grown on rich *adhan* lands with *desi* cotton grown on poor *barani* lands.

The conclusions to be drawn from the investigation of the quality-price relationship are important and of general application to cotton breeding. Improvement of the quality of Indian cotton is a pressing need; but the regression coefficients given above show conclusively that in the present state of the world market, the increase in return with increasing quality is quite disproportionately small. Yield thus becomes by far the most important factor in determining the return per acre from a cotton variety. This does not mean that the breeder should disregard quality and breed entirely for yield but it does mean that while breeding for quality he must pay adequate attention to yield also, because a premium for quality adequate to compensate for more than quite a small loss in yield is not ordinarily realized.

Summary

The relationship between quality and price has been studied in data of spinning tests and commercial valuations of samples grown in Malwa over a period of eight years from 1931 to 1938. It has been shown that the premium for quality is small and this result has been confirmed by an examination of other Indian cottons. Yield, therefore, should receive primary consideration when introducing superior varieties.

Cambodia cotton has been compared with local *desi* cotton and Malvi 9 for yield and money return per acre. It has been shown that Cambodia, in spite of its superior quality, cannot be recommended to the cultivators on account of its lower yield.

The effect of the relationship between quality and price on cotton breeding policy has been discussed and it has been pointed out that a premium for quality adequate to compensate for more than quite a small loss in yield is not ordinarily realized. Therefore, yield and ginning percentage must be taken into account in breeding for superior quality.

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TABLE I

Spinning quality and commercial valuation of cotton samples from Malwa 1931-38

((Malvi 9)

Season	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1931	Good land, I. P. I.*	13½	166	0	0
1932	Med. land, I. P. I.	14	208	—3	—1·44
1932	Poor land, I. P. I.	15½	208	0	0
1932	Narsingarh	17	201	+14	+6·96
1933	Med. and poor land, I. P. I.	17	210	—5	—2·38
1933	Holkar State, Narsingarh, Dhar	15	210	—10	—4·76
1933	Med. land, I. P. I.	17	210	+15	+7·14
1933	Good land, I. P. I.	18	210	+20	+9·52
1934	Piplia	19	226	—5	—2·21
1934	I. P. I. and Ujjain	21	226	—25	—11·06
1935	Med. land, I. P. I.	16	212	+10	+4·72
1935	*Adhan* land, Kharua	15	212	+5	+2·36
1936	Med. land, I. P. I.	15	189	—3	—1·59
1936	*Adhan* land, Kharua	24	189	+5	+2·64
1937	Good land, I. P. I.	19	157	+5	+3·18
1937	Med. land, I. P. I.	23	156½	0	0
1937	*Adhan* land, Kharua	28	156½	+15	+9·58
1938	Good land, I. P. I.	18	270	+10	+3·70
1938	Med. land, I. P. I.	21	278	—18	—6·47
1938	*Adhan* land, Kharua	20	278	0	0

* Institute of Plant Industry, Indore

TABLE II

Spinning quality and commercial valuation of cotton samples from Malwa 1931-38

(Cambodia, Upland)

Season	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1932	Med. land, Dhar	24	204	+10	+4·90
1932	*Adhan* land, Ratlam	22	204	+10	+4·90
1935	Musakheri	14½	212	—3	—1·41
1935	*Adhan* land, Kharua	32	212	+20	+9·43
1936	*Adhan* land, Kharua	26	186	+25	+13·44
1936	*Adhan* land, Kharua	28	186	+10	+5·37
1936	*Adhan* land, Badnawar	29	189	+45	+23·80
1937	I. P. I.	24½	157	+10	+6·37
1937	I. P. I.	26	157	+5	+3·18
1937	I. P. I.	25	157	+10	+6·37
1937	Medium land, Kharua	26	156½	—5	—3·19
1937	Medium land, Kharua	25	156½	—15	—9·58
1937	Medium land, Kharua	30	156½	+25	+15·97
1937	Medium land, Kharua	27	156½	—10	—6·39
1937	*Adhan* land, Kharua	28	156½	—5	—3·19
1937	*Adhan* land, Kharua	29	156½	+20	+12·78
1937	*Adhan* land, Kharua	31	156½	+15	+9·58
1937	*Adhan* land, Kharua	32	156½	+15	+9·58
1937	*Adhan* land, Badnawar	26	157	+5	+3·18
1938	Good land, I. P. I.	30	270	+7	+2·59
1938	Good land, I. P. I.	27	270	+1	+0·37
1938	Good land, I. P. I.	29	270	+7	+2·59

TABLE II—*contd.*

Season	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1938	Good land, I. P. I.	30	270	—2	—0·74
1938	*Adhan* land, Kharua	31	270	+20	+7·41
1938	*Adhan* land, Kharua	28	270	+17	+6·30
1938	*Adhan* land, Kharua	30	270	+20	+7·41
1938	*Adhan* land, Kharua	28	270	+16	+5·92

TABLE III

Spinning quality and commercial valuation of cotton samples from Malwa 1931-38

(Local cotton)

Season	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1931	Good land, I. P. I.	12	166	0	0
1932	Med. land, I. P. I.	10½	208	—5	—2·40
1932	Poor land, I. P. I.	13	208	—25	—12·02
1932	Narsingarh	13	201	+8	+3·98
1933	Med. and poor land, I. P. I.	11	210	—10	—4·76
1933	Holkar State Narsingarh Dhar	12	210	—20	—9·52
1935	Musakheri	11½	212	—15	—7·07
1935	*Adhan* land, Kharua	14	212	+8	+3·77
1836	Med. land, Dhar	11½	183	—5	—2·73

TABLE IV

Spinning quality and commercial valuation of cotton samples from Malwa 1931-38

(Other strains)

Season and strain	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1931					
Malvi 1 .	Good land, I. P. I. .	10	166	+15	+9·04
Malvi 3 .	Good land, I. P. I. .	13	166	+25	+15·06
Malvi 5 .	Good land, I. P. I. .	11	166	+20	+12·05
Malvi 8 .	Good land, I. P. I. .	7	166	+10	+6·02
Malvi mixed selections	Good land, I. P. I. .	14	155	+15	+9·68
Roseum 15 .	Good land, I. P. I. .	7	155	0	0
Indore 1 (Upland)	Good land, I. P. I. .	21	155	+25	+16·13
1932					
Malvi 1 .	Med. land, I. P. I. .	12½	208	—5	—2·40
Malvi 5 .	Med. land, I. P. I. .	12½	208	—3	—1·44
Malvi mixed selections	Med. land, I. P. I. .	13	208	—5	—2·40
Indore 25 (Upland)	Med. land, I. P. I. .	12½	204	—15	—7·35
Indore 1 (Upland)	Med. land, I. P. I. .	14	204	—10	—4·90
Malvi 1 .	Poor land, I. P. I. .	12½	208	0	0
Malvi 5 .	Poor land, I. P. I. .	13	208	—5	—2·40
Malvi 1 .	Narsingarh . .	15	201	+15	+7·46
Malvi 5 .	Narsingarh . .	16	201	+12	+5·97
Indore 25 (Upland)	Dhar . . .	21	204	—10	—4·90
Indore 1 (Upland)	Ratlam . . .	21	204	0	0

TABLE IV—*contd.*

Season and strain	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1933					
Malvi 1 .	Med. and poor land, I. P. I.	10	210	—10	—4·76
Malvi 5 .	Med. and poor land, I. P. I.	14	210	—5	—2·38
Malvi 1 .	Holkar State, Narsingarh, Dhar	13	210	—10	—4·76
Malvil 5 .	Holker State, Narsingarh, Dhar	14	210	—5	—2·38
Malvi 1 .	Good land, I. P. I. .	14	210	+5	+2·38
Malvi 1 . .	Asrawad . . .	13	210	—20	—9·52
Malvi 1 . .	Rau . . .	11	210	—25	—11·90
1934					
Dhar mass Malvi	Dhar . . .	17	226	—20	—8·85
Malvi 1 .	Badnawar . .	12	226	—25	—11·06
Malvi 1 . .	I. P. I. and Ujjain .	16	226	—30	—13·27
Malvi G-51 .	I. P. I. and Ujjain .	12	226	—15	—6·64
Malvi G-16 .	I. P. I. and Ujjain .	15	226	—15	—6·64
1935					
Malvi 9-13 .	Med. land, I. P. I. .	20	212	+15	+7·07
Malvi 9-15 .	Med. land, I. P. I. .	15	212	+5	+2·36
Malvi 9-17 .	Med. land, I. P. I. .	22	212	+20	+9·43
Malvi 9-19 .	Med. land, I. P. I. .	13	212	+18	+8·49
Malvi 9-20 .	Med. land, I. P. I. .	21	212	+25	+11·79
Malvi unselected	Poor land, Musakheri	9	212	—5	—2·36

TABLE IV—*contd.*

Season and strain	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1936					
Malvi 43-1 .	Dhar . . .	9	183	—5	—2·73
Malvi 43-7 .	Dhar . . .	10	183	—12	—6·55
Malvi 43-3 .	Dhar . . .	11	183	+5	+2·73
Malvi 43-2 .	Dhar . . .	13	183	—7	—3·82
Malvi 43-6 .	Dhar . . .	13½	183	—15	—8·19
Malvi 43-5 .	Dhar . . .	13½	183	—5	—2·73
Malvi 43-4 .	Dhar . . .	14	183	0	0
Roseum M .	Dhamnod . .	10½	193	0	0
Nimari local .	Dhamnod . .	11	193	0	0
Nimari M 1 .	Dhamnod . .	12	193	+10	+5·18
Banilla . .	Dhamnod . .	14½	193	—3	—1·55
Nimari M S .	Dhamnod . .	21	193	+15	+7·77
Nimari M V .	Dhamnod . .	17	193	+12	+6·26
Verum 434 .	Dhamnod . .	24	193	+10	+5·18
Malvi 9-15 .	Dhamnod . .	26	193	+25	+12·95
Malvi 9-20 .	Med. land, I. P. I. .	16	189	—7	—3·70
Malvi 9-13 .	Med. land, I. P. I. .	16	189	—5	—2·64
Malvi 9-15 .	Med. land, I. P. I. .	17	189	—7	—3·70
Malvi 9-19 .	Med. land, I. P. I. .	17	189	—5	—2·64
Malvi 9-17 .	Med. land, I. P. I. .	17	189	0	0
Ma vi 9-19 .	Kharua . . .	20	189	+3	+1·59
Malvi 9-17 .	Kharua . . .	23	189	+5	+2·64
Malvi 9-13 .	Kharua . . .	25	189	+10	+5·29

TABLE IV—*contd.*

Season and strain	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1936—contd.					
Malvi 9-20 .	Kharua . . .	28	189	+10	+5·29
Malvi 9-15 .	Kharua . . .	33	189	+15	+7·93
Malwa Upland 5	Badnawar . .	28	189	+35	+18·51
Malwa Upland 4	Badnawar . .	29	189	0	0
I. H. K. (Upland)	Badnawar . .	30	189	+10	+5·29
Malwa Upland 2	Badnawar . .	30	189	+15	+7·93
Malwa Upland 3	Badnawar . .	34	189	+25	+13·44
Malwa Upland 8 A	Badnawar . .	42	189	+35	+18·51
Malwa Upland 8 B	Badnawar . .	43	189	+30	+15·87
1937					
Malvi 43-4 .	Good land, I. P. I. .	20½	157	+5	+3·18
Verum 434 .	Good land, I. P. I. .	26	157	—15	—9·55
Malwa Upland 4	Good land I. P. I. .	19	157	0	0
Malwa Upland 3	Badnawar . .	32	157	+20	+12·74
Malwa Upland 4	Badnawar. . .	27	157	+12	+7·64
Malwa Upland 8 A	Badnawar . .	34	157	—5	—3·18
Malvi 9-13 .	I. P. I. . . .	24	156½	+10	+6·39
Malvi 9-20 .	I. P. I. . . .	20	156½	0	0
Malvi 43-2 .	I. P. I. . . .	18	156½	—10	—6·39
Malvi 43-4 .	I.P. I. . . .	22	156½	—20	—12·78
Malvi 43-5 .	I. P. I. . . .	22	156½	—15	—9·58
Malvi 43-6 .	I. P. I. . . .	21	156½	—10	—6·39
Malvi 9-13 .	*Adhan* land, Kharua .	23½	156½	+15	+9·58
Malvi 9-20 .	*Adhan* land, Kharua .	24	156½	+25	+15·97

TABLE IV—*concld.*

Season and strain	Station	Highest standard warp count	Commercial valuation (Rupees per candy)		
			Broach basis	Difference	Per cent difference
1937—contd.					
Malvi 43-2 .	*Adhan* land, Kharua .	22	156½	—5	—3·19
Malvi 43-4 .	*Adhan* land, Kharua .	24	156½	+20	+12·78
Malvi 43-5 .	*Adhan* land, Kharua .	22	156½	0	0
Malvi 43-6 .	*Adhan* land, Kharua .	22	156½	+5	+3·19
1938					
Indore 1 (Upland)	Med. land, I. P. I. .	29	242	+15	+6·20
Malwa Upland 3	Med. land, I. P. I. .	34	242	+15	+6·20
Malwa Upland 4	Med. land, I. P. I. .	31	242	+10	+4·13
Malwa Upland 8A	Med. land, I. P. I. .	32	242	+5	+2·07
Malvi 43-4 .	Good land, I. P. I. .	16½	270	+2	+0·74
Verum 434 .	Good land, I. P. I. .	21	270	+6	+2·22
Malwa Upland 4	Good land, I. P. I. .	27	270	+3	+1·11
Malvi 43-6 .	Dhar . . .	25	278	—30	—10·79
Malvi 14 .	Dhar . . .	24	278	—25	—8·99
Malvi 22 .	Dhar . . .	26	278	—28	—10·07
Malvi 9-20 .	*Adhan* land, Kharua .	18	278	—5	—1·80
Malvi 43-4 .	*Adhan* land, Kharua .	18	278	—3	—1·07
Malvi 43-5 .	*Adhan* land, Kharua .	18	278	—7	—2·52
Malvi 9-13 .	Med. land, I. P. I. .	24	278	—20	—7·19
Malvi 9-20 .	Med. land, I. P. I. .	22	278	—17	—6·12
Malvi 43-2 .	Med. land, I. P. I. .	22	278	—17	—6·12
Malvi 43-4 .	Med. land, I. P. I. .	21	278	—19	—6·83
Malvi 43-5 .	Med. land, I. P. I. .	21	278	—19	—6·83
Malvi 43-6 .	Med. land, I. P. I. .	22	278	—25	—8·99
Malvi 14 .	Med. land, I. P. I. .	21	278	—19	—6·83
Malvi 22 .	Med. land, I. P. I. .	24	278	—20	—7·19

TABLE V

Yield per acre for Cambodia and desi *cottons in Malwa, 1934*

Station and type of land	Variety	Yield of *kapas*, lb. per acre	Ginning percentage	Yield of lint, lb. per acre
Med. land, Indore	Malvi 9	383	29·5	113
	Cambodia	195	27·7	54
	Local	346	27·3	94
	Standard error	24·6	0·3	
	Significant difference	74	0·9	
Poor land, Indore	Malvi 9	219	28·8	63
	Cambodia	117	26·4	31
	Local	214	26·5	57
	Standard error	11·5	0·4	
	Significant difference	35	1·2	
Adhan land, Sitamau	Malvi 9	1187	32·9	390
	Cambodia	652	30·3	197
	Local	1081	30·0	324
	Standard error	27·5	..	
	Significant difference	82	..	
Med land, Sitamau	Malvi 9	367	31·2	114
	Cambodia	247	30·3	75
	Local	349	30·0	105
	Standard error	17·3	..	..
	Significant difference	52	..	..
Med. land, Badnawar	Malvi 9	347	..	..
	Cambodia	242	..	..
	Local	413	..	..
	Standard error	32·6	..	
	Significant difference	99	..	

TABLE VI

Yield per acre for Cambodia and desi *cottons in Malwa, 1935*

Station and type of land	Variety	Yield of *kapas*, lb. per acre	Ginning percentage	Yield of lint, lb. per acre
Adhan land, Badnawar	Malvi 9	473	31·9	151
	Cambodia	400	31·1	124
	Local	444	30·8	137
	Standard error	65	0·4	..
	Significant difference	..	..	..
Adhan land, Kharua	Malvi 9	1027	31·1	319
	Cambodia	946	30·5	288
	Local	967	29·0	280
	Standard error	60	0·2	..
	Significant difference	..	0·6	..
Adhan land, Ratlam	Malvi 9	1912	31·9	610
	Cambodia	1931	30·1	581
	Local	937	29·6	277
	Standard error	94	..	..
	Significant difference	295	..	..
Adhan land, Sitamau	Malvi 9	940	31·6	297
	Combodia	648	31·3	203
	Local	810	32·1	260
	Standard error	38	0·4	..
	Significant difference	120	..	..

TABLE VII

Yield per acre for Cambodia and desi *cottons in competition experiments at Indore, 1935, 1938 and 1939*

Season	Variety	Yield of *kapas*, lb. per acre	Ginning percentage	Yield of lint, lb. per acre
1935 . . .	Malvi 9	498	33·2	165
	Cambodia . . .	373	31·0	116
	Standard error . .	26·2	..	..
	Significant difference .	88	..	..
1938 . . .	Malvi 9	366	32·8	120
	Cambodia . . .	525	34·0	178
	Local	522	31·3	163
	Standard error . .	38·6	..	..
	Significant difference .	109	..	..
	Malvi 9	263	33·7	89
	Combodia . . .	235	32·5	76
	Local	301	31·1	94
	Standard error . .	20·2	..	..
	Significant difference .	57	..	..
1939 . . .	Malvi 9	322	27·0	87
	Cambodia . . .	212	25·0	53
	Local	303	25·8	78
	Standard error . .	17·5	..	..
	Significant difference .	50	..	..

THE EFFECT OF ENVIRONMENT ON FIBRE MATURITY OF COTTON

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(With one text-figure)

Introduction

ALTHOUGH all changes in plant characters are either environmental or genetical in origin, it was found difficult, in an earlier study of fibre maturity by Gulati and Ahmad [1935], to determine separately the part played by each one of them. The need of further work in this direction being indicated by this work, an extensive study was undertaken with a view to estimating the modifications caused by environmental as distinct from genetical factors. The effect of hybridization on fibre maturity, mean fibre-length and fibre-weight per unit length has since been successfully worked out, and a paper on this subject by Koshal, Gulati and Ahmad [1940] has recently been published. The present paper deals with the second aspect of the study, i.e. fibre maturity in relation to environment, which includes such agronomical factors as preparatory cultivation, locality, sowing date, irrigation, manuring and spacing. So far as is known to the writer this is the first attempt to investigate the effect of these factors on fibre maturity in a systematic manner. The effect of environmental factors on other fibre properties, such as length, weight and strength, has often been observed and studied by previous workers, among whom may be mentioned Burd [1925], Balls [1928] and Barre [1938]. It would be expected that fibre maturity, like other fibre properties, would be affected by agronomical treatments on account of the fundamental property of response to external stimulus possessed by the living protoplasm.

Material

Two sets of samples which were kindly supplied by the Director, Institute of Plant Industry, Indore, formed the material for this investigation. These samples were grown at Sri Ganganagar (Bikaner) on an experimental scale with the primary object of studying the effect of agronomical treatments on the yield of cotton. The first set dealt with the agronomical factors, two sowing dates (one in May and the other in June), presence and absence of preparatory cultivation, heavy and moderate irrigation, three manurial treatments (two fertilizers and control) and two spacings in relation to two cottons P-A/289F. and Mollisoni. A complete set of this kind would have given 96 differently treated samples, i.e. 48 for each cotton, but as all of them were not available, tests were carried out on 26 samples only. These samples,

19 of which belonged to Mollisoni and seven to P-A/289F, could be arranged in pairs so as to enable comparison of one factor at a time.

The second set which was complete included the following factors :— (1) Three sowing dates : (*a*) 22 March 1936, (*b*) 14 May 1936, and (*c*) 5 July 1936 ; (2) Two irrigations: (*a*) adequate, and (*b*) scanty ; (3) (*a*) Presence and (*b*) absence of basal dressings of manure, and (4) three types of top dressings : (*a*) No manure (T_1), (*b*) Well-rotted sheep-dung manure (T_2) and (*c*) Well-rotted sheep-dung manure *plus* ammonium sulphate (T_3). Under this scheme of agronomical lay-out Cambodia cotton was grown in six Rajputana States; but unfortunately only from two of them (Bundi and Ajmere) enough material was available for all the treatments. The material thus consisted of 72 samples, 36 from each locality.

Method

The laboratory technique for determining fibre maturity of cotton has been described by Gulati and Ahmad [1935] and Ahmad and Gulati [1936] previously. The same technique was employed in this study, a notable feature of which was that the samples were tested without any knowledge of their agronomical history so as to preclude all possibilities of personal bias in the results.

Results

The maturity percentages of the various samples belonging to both the sets are presented in Tables I and II. In Table I, the 26 samples of the first set are arranged in pairs such that the effect of the presence or absence of each agronomical factor is compared at a time. The second set is arranged in Table II according to the plan of the experiment. A separate discussion is devoted to each of these sets.

Discussion of results

First set

The maturity results of the first set are also shown in Fig. 1, where the 26 values are plotted in descending order of magnitude and according to cottons.

From this diagram it will be readily noticeable that the best combination of agronomical factors is not the same for both P-A/289F and Mollisoni. Whereas May sowing, presence of preparatory cultivation, heavy irrigation, Nicifos manure and single spacing produce the highest maturity value of P-A/289F, June sowing, absence of preparatory cultivation, no manure, moderate irrigation and single spacing help Mollisoni to attain its biggest maturity value. It is interesting to note that the two cottons find their highest maturity values with four opposing agronomical factors out of the five studied.

It will also be noted that the samples showing the highest and the lowest maturity values in each cotton are not treated differently in respect of all the five agronomical factors. In either case it is only a change in two of these factors that appears to be responsible for the maximum variation in the percentage of mature hairs. For P-A/289F a change of 19 in the percentage

of mature hairs is found to be due to a change of sowing date and irrigation—May sowing with heavy irrigation yielding the highest value, against June sowing with moderate irrigation yielding the lowest maturity value. In Mollisoni the maximum difference of 16 per cent in maturity was produced again by two factors, namely presence or absence of cultivation and single or double spacing.

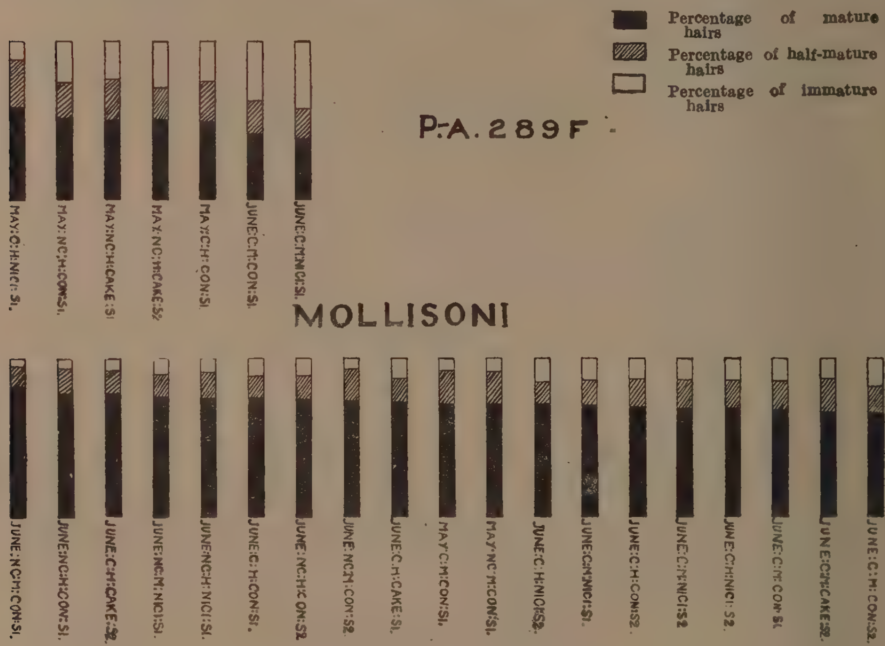

FIG. 1. Maturity results of the first set

May = May sowing; June = June sowing; C = preparatory cultivation; H = heavy irrigation, Nici = Nicifos manuring; S_1 = single spacing; NC = no preparatory cultivation; M = moderate irrigation; Con. = control (no manure); Cake = castor cake; S_2 = double spacing]

The differential response of the two cottons to various agronomical factors and also the importance of early sowing date with heavy irrigation for P-A/289F and the absence of preparatory cultivation with single spacing for Mollisoni, thus, become evident.

The single-factor arrangement in Table I will now be examined in detail. It has been stated already that in this table the results of alternative treatments for each agronomical factor are compared separately.

The reason for adopting such comparisons was that the analysis of variance could not be applied to such incomplete data and the appropriate standard error from the actual data could not be evaluated. However, in such a comparative study we could take avantage of the standard error calculated for different sizes of sample for this fibre property by Gulati and

TABLE I

Maturity results of set 1 arranged in pairs so as to sort out the effect of each agronomical factor

Factors	Percentages			Factors	Percentages			Agronomical treatment
	Mature	Half-mature	Immature		Mature	Half-mature	Immature	
Sowing date								
P-A 289F	...	...	...	P-A 289F	...	...	...	
Mollisoni—				Mollisoni—				
May	71	21	8	June	67	18	15	C : M : Con : S1
Do.	71	20	9	,,	82	13	5	NC : M : Con : S1
Preparatory cultivation								
P-A 289F—								
No cultivation	51	23	26	Cultivation	49	25	26	
Mollisoni—								
No cultivation	82	13	5	Cultivation	67	18	15	June : M : Con : S1
Do.	73	20	7	Do.	66	16	18	June : M : Con : S2
Do.	76	14	10	Do.	70	16	14	June : M : Nici : S1
Do.	74	15	11	Do.	69	18	13	June : H : Con : S2
Do.	75	16	9	Do.	71	14	15	June : H : Nici : S1
Do.	78	16	6	Do.	75	14	11	June : H : Con : S1
Do.	71	20	9	Do.	71	21	8	May : M : Con : S1
Irrigations								
P-A 289F—								
Mollisoni—								
Heavy	78	14	8	Moderate	66	21	13	June : C : Cake : S2
Do.	69	18	13	Do.	66	16	18	June : C : Con : S2
Do.	74	15	11	Do.	73	20	7	June : NC : Con : S2
Do.	71	14	15	Do.	70	16	14	June : C : Nici : S2
Do.	68	18	14	Do.	68	18	14	June : C : Nici : S2
Do.	75	16	9	Do.	76	14	10	June : NC : Nici : S1
Do.	78	16	6	Do.	82	13	5	June : NC : Con : S1
Manure								
P-A 289F—								
Cake	50	24	26	Control (no manure)	51	23	26	May : NC : H : S1
Nicifos	39	18	43	Do.	41	21	38	June : C : M : S1
Do.	58	20	12	Do.	49	25	26	May : C : H : S1

TABLE I—*contd*

Factors	Percentages: Mature	Half-mature	Immature	Factors	Percentages: Mature	Half-mature	Immature	Agronomical treatment
Mollisoni—								
Cake	78	14	8	Control (no manure)	69	18	13	June : C : H : S2
Do.	66	21	13	Do.	66	16	18	June : C : M : S2
Do.	72	15	13	Do.	75	14	11	June : C : H : S1
Do.	78	14	8	Nicifos	68	18	14	June : C : H : S2
Do.	72	15	13	Do.	71	14	15	June : C : H : S1
Do.	66	21	13	Do.	68	18	14	une : C : M : S2
Nicifos	76	14	10	Control (no manure)	82	13	5	June : NC : M : S1
Do.	71	14	15	Do.	75	14	11	June : C : H : S1
Do.	75	16	9	Do.	78	16	6	June : NC : H : S1
Do.	68	18	14	Do.	69	18	13	June : C : H : S2
Do.	68	18	14	Do.	66	16	18	June : C : M : S2
Do.	70	16	14	Do.	67	18	15	June : C : M : S1
Spacings								
P-A 289F—								
Single	50	24	26	Double	50	21	29	May : NC : H : Cake
Mollisoni—								
Single	82	13	5	Double	73	20	7	June : NC : M : Con
Do.	75	14	11	Do.	69	18	13	June : C : H : Con
Do.	78	16	6	Do.	74	15	11	June : NC : H : Con
Do.	71	14	15	Do.	68	18	14	June : C : H : Nici
Do.	70	16	14	Do.	68	18	14	June : C : M : Nici
Do.	67	18	15	Do.	66	16	18	June : C : M : Con
Do.	72	15	13	Do.	78	14	8	June : C : H : Cake

H = Heavy irrigation (eleven waterings)
M = Moderate irrigation (six waterings)
Con = Control or no manure
Cake = Castor-cake at 30 lb. N per acre
Nici = Nicifos 22/18 at 30 lb. N per acre
S1 = 6 in. plant-to-plant spacing
S2 = 12 in. plant-to-plant spacing
C = With preparatory cultivation
NC = Without preparatory cultivation

NOTE.—The following crops were previously grown without manuring on the land used for the setests: —

Season	Crop
Kharif 1932	Fallow
Rabi 1932-33	Wheat
Kharif 1933	Fallow
Rabi 1933-34	Wheat

Ahmad [1935]. According to this, the maximum sampling error for a sample of 500 fibres, as was tested for each sample under discussion, is 8·9 for $P=0\cdot05$. Any difference exceeding this value is, therefore, tentatively regarded as signifiant in the following discussion.

(*a*) *Sowing date.*—The effect of this factor could be isolated for Mollisoni only, two pairs of values being available for the purpose. In the first pair the differences in maturity percentages are not significant, but they are so in the second. June sowing yields higher percentage of mature hairs than May sowing. In order to see why June sowing failed to produce a similar trend in the first pair also, it is necessary to take into account the other agronomical treatments received by either pair of samples. Looking at these treatments from the last column in Table I, it is found that the two pairs differ from each other only in respect of presence or absence of preparatory cultivation. Presence of preparatory cultivation appears to nullify the effect of June sowing in the first pair, while its absence heightens the effect of June sowing in the second pair. It is, therefore, concluded that June is a favourable time for sowing Mollisoni, but only in the absence of preparatory cultivation.

(*b*) *Preparatory cultivation.*—The presence or absence of this factor did not affect the maturity of P-A/289F in the one pair of samples available for the purpose.

For Mollisoni, out of seven pairs available for the study of this factor, six show a trend of higher maturity for samples without preparatory cultivation than those grown with preparatory cultivation. It is only in one of the six pairs showing the superiority of the absence of preparatory cultivation that there is a significant increase in the percentage of mature hairs over the corresponding sample grown after the preparatory cultivation. The differences in the remaining five pairs are non-significant. The similarity of the trend in six pairs, however, indicates a preponderating effect of the absence of preparatory cultivation. The maturity percentages in the seventh pair are similar for the opposing treatments. A perusal of the last column of Table I again shows that the different behaviour of this pair is associated with its being May sown, while all others are June sown. The absence of preparatory cultivation is thus observed to be beneficial to the maturity of Mollisoni when it is June sown.

(*c*) *Irrigation.*—Like sowing date, this factor was not represented alone in the available samples of P-A/289F. However, in an earlier part of the discussion it has been noticed already that a combination of May sowing with heavy irrigation gave the highest value, while June sowing with moderate irrigation yielded the lowest maturity value for P-A/289F.

As regards Mollisoni there are seven pairs of samples. Four of these pairs bring out a trend of higher maturity for heavy irrigation ; two pairs indicate the opposite trend of superiority of the moderate irrigation and in one pair the two types of irrigation yield similar values. Among the four pairs showing higher percentages of mature hairs for heavy irrigation, significant improvement in maturity is noticed only in one pair. It is in this pair, therefore, that the effect of heavy irrigation is least eclipsed by other factors, while the interactions with other factors appear to lower the good effect of this treatment.

The conclusion from this study is that heavy irrigation under certain conditions is beneficial to both the cottons. Afzal [1937] also found that maturity generally increased with irrigations in the case of P-A/4F.

(*d*) *Manures.*—The effect of Nicifos and cake maures is compared to no-manure in three pairs for P-A/289F. Nicifos yields significantly higher maturity values than no-manure in one case, but not in the other. The differential response of the two pairs is again found to be associated with different sowing dates. Nicifos proved useful when applied with May sowing, but not with June sowing. The application of cake made no difference from no-manure in the third pair of P-A/289F.

Mollisoni presented 12 pairs of samples for this study. Comparisons between cake and Nicifos, and cake and no-manure are available in three pairs for each. The application of cake scored a significantly higher maturity than Nicifos or no-manure in one of the three pairs for each, but its effect varied non-significantly in the other two pairs. Nicifos is compared with no-manure in the remaining six pairs. In four of these, no-manure showed a trend of higher maturity than Nicifos, evidently due to the beneficial superimposing effect of heavy irrigation in three of them, and in the fourth due to a similar effect of the absence of cultivation. The effect of Nicifos rises above that of no-manure in the remaining two pairs, but on account of the differences being non-significant, the cause of noted variation cannot be ascribed with any certainty.

The above discussion brings out the beneficial effect of Nicifos to P-A/289F and of cake and no-manure to Mollisoni in suitable combinations with other factors.

(*e*) *Spacings.*—P-A/289F is again represented by one pair for this study. The two kinds of spacings do not lead to any difference in the maturity percentages of the two samples in the pair. In Mollisoni out of seven pairs, six show a trend of higher maturity for single than for double spacing. The differences are again significant only in one of these pairs and not in others. In the seventh pair, although the differences are also non-significant, the trend goes in the opposite direction, i.e. double spacing leading to a somewhat maturer cotton than single spacing. Cake manure appears to be the second helpful factor in this pair. On the whole, single spacing is more useful than double spacing to Mollisoni, although P-A/289F did not react to the influence of spacing in the studied pairs of samples.

It must, however, be mentioned that conclusions in the above comparisons are based on a few or even single pair of values and hence cannot be recommended for wider application.

Second set

Table II shows the maturity percentages of the samples of Cambodia (Indore) cotton grown at Bundi and Ajmere which comprise set 2 of the material mentioned before.

It should be mentioned here that though Cambodia cotton is familiarly associated with South India, it is also fairly widely grown in Central India. These results, therefore, while having a general appeal for workers on agrotnomy of cotton, should prove especially useful to cotton cultivators in Central India.

TABLE II

Maturity results of set 2

Agronomical treatments*				Bundi			Ajmere		
Sowing date	Irrigation	Basal dressing	Top dressing	Mature (per cent)	Half-mature (per cent)	Immature (per cent)	Mature (per cent)	Half-mature (per cent)	Immature (per cent)
March . . .	Adequate .	No B . .	T1	49	35	16	63	20	17
			T2	57	28	15	62	23	15
			T3	69	20	11	66	22	12
		B . . .	T1	57	28	15	56	25	19
			T2	58	25	17	68	22	10
			T3	63	24	13	59	25	16
	Scanty .	No B . .	T1	62	24	14	70	20	10
			T2	68	21	11	64	24	12
			T3	62	27	11	66	22	12
		B . . .	T1	54	34	12	61	22	17
			T2	58	30	12	66	24	10
			T3	53	37	10	60	28	12
May . . .	Adequate .	No B . .	T1	54	31	15	64	21	15
			T2	63	27	10	59	28	13
			T3	66	22	12	65	26	9
		B . . .	T1	61	29	10	66	20	14
			T2	58	27	15	66	21	13
			T3	57	28	15	67	19	14
	Scanty .	No B . .	T1	57	30	13	60	25	15
			T2	55	32	13	56	31	13
			T3	63	29	8	62	25	13
		B . . .	T1	52	34	14	60	23	17
			T2	48	37	15	60	21	19
			T3	60	26	14	60	24	16
July	Adequate .	No B . .	T1	53	27	20	64	21	15
			T2	67	21	12	64	23	13
			T3	72	19	9	69	20	11
		B . . .	T1	48	38	14	60	21	19
			T2	52	36	12	61	28	16
			T3	58	26	16	66	17	17
	Scanty .	No B . .	T1	47	29	24	58	25	17
			T2	46	40	14	61	23	16
			T3	46	36	18	61	26	13
		B . . .	T1	42	34	24	53	32	15
			T2	41	40	19	51	30	19
			T3	55	26	19	67	22	11
		Total .	...	2,031	1,057	512	2,241	844	515
		Mean (per cent)	...	57	29	14	62	24	14

* Adequate = Irrigation at 15 days interval during the hot weather and one or two irrigations after rains at suitable intervals

Scanty = One or two irrigations at start for germination followed by irrigation frequency to prevent wilting of the crop; one or two post-rain irrigations as in adequate

B = Basal dressing of well-rotted sheep-dung manure at 32 mds. per acre and ammonium sulphate at 50 lb. per acre

No B = No basal dressing

T1 = No top dressing

T2 = Top dressing of sheep dung at 32 mds. per acre

T3 = Top dressing of sheep dung at 32 lb. per acre and ammonium sulphate at 50 lb. per acre supplied mixed together after the mixture had been allowed to stand for five days

Top dressings were given after the rains were established, but not before the 3rd week of July

As the experiment was well planned and the samples from all the treatments were available, analysis of variance could be applied to the data. Variance due to each factor included in the experiment could, thus, be sorted out and studied. The results of this analysis are given below :—

Analysis of variance

(Per cent mature hairs)

Agronomical factors	Degrees of freedom	Sum of squares	Mean square	F
A.—Average effect—				
(L) Localities	1	612·5	612·5	33·40**
(S) Sowing dates	2	261·5	130·8	7·13**
(I) Irrigations	1	280·0	280·0	15·27**
(B) Basal dressings	1	156·0	156·0	8·51**
(T) Top dressings	2	319·0	159·5	8·70**
B.—First order interactions*—				
$L \times S$	2	90·3	45·2	2·46
$L \times I$	1	26·9	26·9	1·47
$L \times B$	1	43·6	43·6	2·38
$L \times T$	2	63·6	31·8	1·73
$S \times I$	2	317·3	158·7	8·65**
$S \times B$	2	46·0	23·0	1·25
$S \times T$	4	147·5	36·9	2·01
$B \times I$	1	8·7	8·7	0·47
$B \times T$	2	21·7	10·8	0·59
$I \times T$	2	50·3	25·2	2·37
Residual	45	825·1	18·3	

* Since there was no replication, the higher-order interactions together were considered as residual in the above analysis.

** Denote 1 per cent point of significance.

It will be noted that the variance due to each of the five factors is significant at 1 per cent level [Snedecor, 1937], showing that each factor is capable of modifying the maturity of this cotton to an appreciable extent. From

the first-order interactions, only that between sowing date and irrigation has a significant variance, while all others are non-significant. The absence of significance for the other interactions suggested that most of these factors have no differential effect upon the maturity of the fibre.

Each factor is discussed below in greater detail.

(*a*) *Locality.*—The average maturity values from the two localities yield significantly different maturity percentages—Ajmere producing more mature cotton than Bundi.

Locality	Mature	Half-mature	Immature
Ajmere	62	24	14
Bundi	57	29	14

Standard error $\pm$ 0·71

(*b*) *Sowing date.*—Out of the three sowing dates—March, May and July—March yields the highest maturity percentages and July the lowest. The trend is noticeable in both the localities, although the fall in maturity from May to July is significant in Bundi and not in Ajmere.

Locality	Percentage of mature hairs		
	March	May	July
Bundi	59	58	52
Ajmere	63	62	61

Standard error $\pm$ 1·23

(*c*) *Irrigation.*—Adequate irrigation was found to produce higher percentages of mature hairs as compared with scanty irrigation in both the localities in May and July sowings, but in March this was not the case as will be seen from the mean values given below. In other words, with the benefits of early sowing even scanty irrigation served the purpose so far as fibre maturity is concerned, but with late sowing heavier irrigation was necessary to give a sufficiently high fibre maturity. It was due to this differential effect in respect of sowing dates and irrigation that the interaction $S \times I$ had a significant variance value.

It may be emphasized that the final effect of irrigation on any crop must be judged in relation to the rainfall record of the season in question. Here, for instance, it is found that the March-sown crop gets the benefit of local rains during the maturation period equally for both adequate and scanty irrigations, leading to almost similar maturity values. But the later crops, i.e. May and July sown get the monsoon rains during their vegetative phase

of growth and, hence, the two types of irrigation after the rains affect the maturity of the lint of the crop differentially.

Percentage mature hairs

Sowing date	Bundi		Ajmere	
	Adequate	Scanty	Adequate	Scanty
March	59	59·5	62	64·5
May	60	56	64·5	60
July	58	46	64	58·5

Standard error $\pm$ 1·75

(*d*) *Basal dressings*.—A comparison of basal dressing with no basal dressing shows that the latter is on the whole better than the former for obtaining maturer cotton. The effect again is significant at Bundi but not at Ajmere. Mean values for these treatments are given below :—

Percentage mature hairs

Locality	No B	B
Bundi	59	54
Ajmere	63	62

Standard error $\pm$1·01

(*e*) *Top dressing*.—The three treatments considered under this head are :—T_1 or no top dressing, T_2 or top dressing with sheep dung, and T_3 or top dressing with sheep dung and ammonium sulphate. The average muturity for T_1 is found to be the lowest, while that for T_3 is the highest at both the places as seen below :—

Percentage mature hairs

Locality	T_1	T_2	T_3
Bundi	53	56	60
Ajmere	61	61·5	64

Standard error $\pm$ 1·23

The improvement affected by T_3 is noteworthy as it persists not only with localities but also with respect to sowing date, irrigation and basal dressings.

Percentage mature hairs

Sowing date	Agronomical factor		
	T_1	T_2	T_3
March	59·0	62·6	62·2
May	59·2	58·1	62·5
July	53·1	55·4	61·8

Standard error ± 1·51

Irrigation	T_1	T_2	T_3
Adequate	57·9	61·2	64·8
Scanty	56·3	56·2	59·6

Standard error ± 1·23

Basal dressing	T_1	T_2	T_3
No B	58·4	60·2	64·3
B	55·8	57·3	60·4

Standard error ± 1·23

It is therefore suggested that top dressing of sheep dung and ammonium sulphate may be used on a larger scale for improving the fibre maturity of cottons of Cambodia type wherever necessary. It would be interesting to perform well-designed experiments to confirm this conclusion and to extend it to other cottons. It may be pointed out here that, whereas the application of basal dressing of sheep dung with ammonium sulphate did not prove helpful in improving fibre maturity, the application of sheep dung and ammonium sulphate as top dressing, after the rains were well established, improved the maturity of this cotton. The usefulness of top dressing of manure to cotton yield has been previously shown by Wells [1928]. The effectiveness of the manure used in the present experiment in top dressing and not in basal dressing appears to be due to the movement of sulphate of ammonia in the soil. Sahasrabudhe and Gokhale [1934] found that this salt diffuses in the soil through an equal distance on all sides (6 in. in six weeks) ; but the

quantity diffused is greater in the downward direction and smaller in the upward direction than along the horizontal. This would explain how more of it may be available to the root-system of cotton plant from the top dressing than from the basal dressing.

Summary

The effect of environment, as provided by agronomical factors, on fibre maturity of cotton, for which material was kindly supplied by the Institute of Plant Industry, Indore, is described in this paper.

The material consisted of two sets of samples. The first set consisted of samples of P-A/289F and Mollisoni cottons grown at Sriganganagar (Bikaner). The agronomical factors included in this experiment were: (*i*) Sowing dates in May and June, (*ii*) presence and absence of preparatory cultivation, (*iii*) heavy and moderate irrigations, (*iv*) cake, Nicifos and no-manure, and (*v*) 6 and 12 in. spacings. From a study of these results the following conclusions are drawn, which should be regarded as tentative owing to the small number of samples in this set :—

(1) Out of the two sowing dates, May suited P-A/289F, while June helped Mollisoni to attain its highest fibre maturity.

(2) Preparatory cultivation did not prove beneficial to either of the two cottons in respect of fibre maturity. Its absence, however, helped Mollisoni when it is June sown.

(3) Heavy irrigation comprising 11 waterings as compared to moderate irrigation of 6 waterings was helpful in raising the fibre maturity of both the cottons. Heavy irrigation with May sowing formed a good combination for P-A/289F.

(4) The application of Nicifos to P-A/289F was evidently better than no-manure when the cotton was sown in May, while cake and no-manure suited Mollisoni better than Nicifos.

(5) Six inch spacing as compared with 12 inch spacing improved the fibre maturity of Mollisoni.

The second set consisted of samples of Cambodia cotton grown in two Rajputana States—Bundi and Ajmere. The agronomical factors studied in this experiment were: (*i*) three sowing dates in March, May and July, (*ii*) adequate and scanty irrigations, (*iii*) presence and absence of basal dressing of manure, and (*iv*) three top dressings of manure. The following conclusions are drawn from the results :—

(1) Locality has a significant effect upon maturity percentage, Ajmere yielding higher percentages of mature fibres as compared with Bundi.

(2) The earlier-sown samples gave higher percentages of maturity in both the localities. Thus, sowing in March proved the best and sowing in July the worst in respect of this property. The bad effects of late sowing could, however, be remedied by heavy irrigation.

(3) Adequate irrigation yielded higher fibre maturity than scanty irrigation.

(4) The application of sheep dung at the rate of 32 mds. per acre *plus* ammonium sulphate at the rate of 50 lb. per acre as basal dressing had a depressing effect upon fibre maturity as compared with no basal dressing.

(5) Top dressings with sheep dung alone (T_2) and sheep dung *plus* ammonium sulphate (T_3) as compared to no top dressing (T_1) had a beneficial effect upon maturity percentage, T_3 giving better results than T_2. Thus, the application at the same rate of the same manure, i.e. sheep dung *plus* ammonium sulphate did not prove beneficial as a basal dressing, but proved beneficial when applied as a top dressing.

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GROWTH STUDIES IN RICE

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INTRODUCTION

ENGLEDOW [1923, 1924, 1926, 1928, 1930] in a series of valuable articles relating to growth, development and yield in the wheat plant in England stressed the importance of early tiller formation as an index of high-yielding capacity in a variety. Further, he discovered that there is what he termed a critical period in tillering which marks the time up to which spacing does not influence tillering and before which are formed those tillers that survive to harvest and bear ears.

Joshi [1923] gave an account of the effects of environmental factors on growth and tillering in rice in the Bombay province, while Bhide [1927] in Bombay also expressed growth in rice in terms of height of plant.

Ramiah and Narasimham [1936] described several phases of growth in the rice plant under Madras conditions, and Rao [1937] published data showing correlation of some characters, including tillering, on yield in rice in Madras.

Growth studies were carried out as part of the programme of work during the five-year period of a grant from the Imperial Council of Agricultural Research for rice research in Burma, the main object being to find out the different phases of growth and development in the rice plant and whether there is a critical period in tillering as in the case of wheat. The importance of tillering in connection with yield in cereals is generally recognized, and this article, which gives a summary of the earlier results of growth studies in rice under Lower Burma conditions, has been written at the request of the Imperial Council of Agricultural Research.

The studies were conducted on the Rice Research Station at Hmawbi in Lower Burma, where the crop is rain-fed and grown during the period of the south-west monsoon. The rainfall on the Station averages about 96 in. per annum, and almost the whole of this rainfall is from May till November, the highest precipitation being in the months of July and August. The soil consists of a stiff alluvial clay, the pH value being 6·1 for the soil and 35 for the sub-soil. The average yields are about 1,600 lb. of paddy to the acre.

Method

For the experiment, one half-acre plot of average fertility was used and random samples were taken from two pure lines, A16-34 and C15-10, in 1933 and from three pure lines, A16-34, C19-26 and C15-10, in 1934. The pure line A16-34 is early maturing, C19-26 is intermediate and C15-10 is late maturing. The seedlings were raised in nurseries in the usual way and transplanted at the age of 35 days. Planting was carried out in rows at two different spacings of 8 in. by 8 in. (close spacing) and 18 in. by 18 in. (wide spacing) for each pure line, the end and side rows being left out of the experiment to eliminate border effects. The close spacing is about the normal under ordinary cultivation conditions, while the wide spacing is used on plant breeding areas where individual plants have to be examined.

Thirty-six samples of four plants each were taken at random for study from each pure line for each spacing, except in the year 1933, when 32 samples only were taken in wide spacing in A16-34 and C15-10. The main stems were labelled by means of small zinc tags at the time of planting, and the tillers when they appeared above ground level were also labelled by small zinc tags so that growth and development of the main stems and tillers could be studied and the flowering dates and final yield of grain per tiller compared with the date of tiller formation. By this means it was also possible to record the death rate in tillers according to the date of tiller formation.

Data were recorded weekly from the 1st week of August onwards till the pure lines were harvested, and further data were recorded in the laboratory after the plants and grain were thoroughly sun-dried.

Tillering

Tiller formation

In Table I are shown the average number of tillers formed at different dates in each pure line for each spacing over two years in the case of A16-34 and C15-10 and for one year in the case of C19-26. The percentages of tillers formed that survived, the percentage contributions of tillers formed at different dates to the final stem population and the percentage contributions by different tillers to the final yield of grain are also shown. In that Table the letters A, S, O, N represent the months of August, September, October and November respectively, while the numbers at the base of these letters represent the week of the month in which data were recorded. M denotes the main stem.

Tillering commenced about a fortnight after transplanting and continued fairly rapidly in lateral branching order till about the first week of September in close planting, and then it slowed down rapidly. In the first year of the experiment tillering continued rapidly in wide spacing till about the second week of September, but in the second year it continued till about the third week of October, and this may be explained by the fact that the plants in the second year of the experiment received a check in growth early in the growing season on account of heavy rains accompanied by strong winds. In wide planting, a few tillers continued to be formed up till about ten days before flowering, that is, from five to six weeks before ripening, but the quantity of filled grain on these late tillers was very small.

TABLE

Average number of main stems and

Spacing	Strain		M	A_1	A_2	A_3
Close (8-in. × 8 in.)	A 16-34	Tillers formed (includes main stems)	144·00	1·00	15·00	83·00
		Percentage of tillers that survived	90·00	...	90·00	89·00
		Percentage to show the constitution of whole stem population at harvest	28·00	...	3·00	16·50
		Percentage yield in grain	34·66	...	2·98	15·63
	C 15-10	Tillers formed (includes main stems)	144·00	27·00	123·50	175·00
		Percentage of tillers that survived	84·00	88·00	78·50	76·50
		Percentage to show the constitution of whole stem population at harvest	22·00	4·00	18·00	24·00
		Percentage yield in grain	29·63	...	19·68	23·98
	C 19-26	Tillers formed (includes main stems)	144·00	5·00	52·00	86·00
		Percentage of tillers that survived	62·00	60·00	50·00	57·00
		Percentage to show the constitution of whole stem population at harvest	29·00	1·00	8·00	19·00
		Percentage yield in grain	39·00	...	7·85	21·20
Wide (18 in. × 18 in.)	A 16-34	Tillers formed (includes main stems)	136·00	1·00	13·50	69·00
		Percentage of tillers that survived	94·50	...	85·00	81·50
		Percentage to show the constitution of whole stem population at harvest	12·50	...	1·00	4·50
		Percentage yield in grain	15·60	...	...	5·86
	C 15-10	Tillers formed (includes main stems)	136·00	18·00	80·50	135·50
		Percentage of tillers that survived	43·00	76·00	75·50	79·00
		Percentage to show the constitution of whole stem population at harvest	8·00	0·50	4·00	7·00
		Percentage yield in grain	10·63	...	4·72	8·05
	C 19-26	Tillers formed (includes main stems)	144·00	...	22·00	66·00
		Percentage of tillers that survived	74·00	...	73·00	59·0
		Percentage to show the constitution of whole stem population at harvest	15·00	...	2·00	6·00
		Percentage yield in grain	21·93	...	...	7·51

I

tillers for the years 1933 and 1934

A_4	S_1	S_2	S_3	S_4	S_5	O_1	O_2	O_3	O_4	N_1	N_2
129·00	144·50	42·50	25·00	35·00	17·00	16·50	11·50	2·00	...	...	...
74·50	27·50	51·00	21·00	26·50	18·00	16·00	21·50	...	...	...	...
22·00	17·50	4·50	2·00	3·50	1·00	1·50	1·00	...	...	...	...
23·16	13·58	3·59	1·73	3·02	0·49	0·73	0·49	...	...	...	...
176·50	187·50	38·50	20·00	10·50	17·50	18·50	14·00	8·00	9·00	4·00	0·50
50·50	27·50	30·00	11·50	14·00	16·00	19·00	18·50	12·50	11·50	...	...
16·00	9·00	2·00	0·50	0·50	1·00	1·50	1·00	...	0·50	...	...
14·25	7·50	1·45	0·24	0·32	0·89	1·05	0·81	0·16	...	...	...
106·00	114·00	20·00	14·00	15·00	43·00	41·00	28·00	7·00	4·00	4·00	...
57·00	26·00	25·00	21·00	20·00	23·00	24·00	32·00	14·00	...	...	...
20·00	10·00	2·00	1·00	1·00	3·00	3·00	3·00	...	...	...	...
18·57	6·65	...	...	...	2·32	2·32	2·09	...	...	...	...
118·00	201·00	198·00	168·50	234·00	120·50	130·50	102·50	30·00	26·50	3·50	...
84·00	81·50	80·00	80·00	72·50	69·00	58·00	61·50	26·50	4·00	...	...
8·00	14·50	12·50	12·00	12·00	8·00	7·00	5·50	2·00	0·50	...	...
9·93	17·00	12·97	11·75	10·89	6·77	4·63	3·41	1·16	...	...	...
178·50	321·00	195·00	161·50	229·50	161·00	229·00	142·00	128·50	158·50	118·50	38·00
74·50	75·00	70·00	68·00	65·50	60·00	52·00	46·50	57·00	33·50	9·50	4·50
8·50	15·50	8·50	7·50	10·00	7·00	7·50	4·50	5·00	4·50	1·50	0·50
10·22	16·97	8·90	7·27	9·91	7·13	6·26	3·29	3·28	2·08	0·80	...
77·00	142·00	54·00	64·00	111·00	119·00	122·00	107·00	79·00	82·00	62·00	12·00
61·00	61·00	50·00	56·00	59·00	58·00	41·00	51·00	62·00	50·00	18·00	17·00
7·00	12·00	4·00	5·00	9·00	10·00	7·00	8·00	7·00	6·00	2·00	...
8·12	15·73	4·03	5·85	9·93	9·62	5·03	5·90	4·11	2·24	...	...

In both wide and close spacing, the number of tillers formed in the pure line C15-10 was greater by more than 50 per cent than in A16-34. The pure line C15-10, though it is late in maturing, commenced to produce tillers earlier than the earliest strain, A16-34, and also at a greater rate. The pure line C19-26 also commenced to produce tillers earlier and at a greater rate than A16-34. These data therefore indicate : (1) that good tillering is associated with the early production of tillers and (2) that tillering is not influenced by spacing only and varietal differences play an important rôle.

Death rate in tillers

The data in Table I indicate that the death rate is very much higher in the late-formed than in the early-formed tillers. In close spacing, in all the pure lines, the main stems, with the tillers formed up to the first week of September, constituted the bulk of the final stem population in the samples as those formed after that date only constituted from 7 to 14 per cent. In wide spacing, the later-formed tillers constituted a much larger proportion of the final stem population than in close spacing, and effective tillering in this case continued up till about the third week of October. The data do not indicate that there is a well-defined critical period for tillering in rice under Lower Burma conditions, but they indicate clearly, in the close spacing, the important contributions of tillers formed up to about the first week of September to the final stem population. In tillers formed from that time onwards the death rate is also much higher than in early-formed tillers and in main stems. In wide spacing, effective tillering continued till about the third week of October.

Yields

In Table II are shown the average yields, lengths of the panicles and percentages of fully filled grain from main stems and from tillers formed at different dates. The percentages of fully filled grain were worked out on account of the importance of evenness in the size of grain in Burma, particularly for export to high grade markets, and a feature of the results is that the percentages of fully filled grain are smaller than may be expected even on the main stems, although the percentages on main stems are higher than on the later-formed tillers.

In all cases, the panicles on the main stems and early tillers were longer than in the later tillers, and the percentages of filled grain and also the weights of grain were higher in the main stems and early tillers than on late tillers. The rates of decrease in the length of panicle were proportionately less than in the weight of grain per panicle, thus showing that the density of the panicle on later-formed tillers was much less than on early-formed tillers.

The data in Table I show that in close spacing the main stems, together with the tillers formed up till the second week in September, contributed 90 per cent to the yield in A16-34, 93 per cent in C19-26 and 95 per cent in C15-10. In wide spacing, the main stems, together with the tillers formed up till the second week of September, contributed only 62 per cent to the final yield in A16-34, 54 per cent in C19-26 and 52 per cent in C15-10 as effective tillering in this case continued till about the third week of October.

TABLE II

Average yields, lengths of panicle and percentages of fully filled grain from main stems and tillers

Spacing	Strain	Stems	Length of panicle in cm.		Filled grain (per cent)		Yield of filled grain per panicle in gm.	
			1933	1934	1933	1934	1933	1934
Close (8 in. × 8 in.)	A 16-34	M	25·43± ·10	25·13± ·14	76	80	3·29± ·05	3·38± ·05
		A_2	25·60± ·25	...	78	...	3·25± ·07	...
		A_3	24·26± ·13	23·58± ·21	76	82	2·78± ·05	2·74± ·08
		A_4	24·30± ·14	22·77± ·20	75	82	2·73± ·04	2·41± ·07
		S_1	22·36± ·15	23·15± ·17	74	79	2·03± ·04	2·26± ·06
		S_2-S_4	23·12± ·31	22·89± ·23	73	70	2·04± ·07	2·35± ·07
		O_1-O_3	...	20·36± ·41	...	67	...	1·35± ·11
	C 15-10	M	26·05± ·08	25·24± ·10	85	77	3·12± ·03	2·97± ·05
		A_2	25·19± ·27	23·55± ·14	88	71	2·91± ·05	2·25± ·05
		A_3	25·29± ·13	22·59± ·14	85	70	2·73± ·04	1·94± ·05
		A_4	23·82± ·14	22·32± ·17	86	71	2·28± ·04	1·89± ·06
		S_1	22·75± ·18	21·99± ·19	82	65	2·04± ·05	1·74± ·08
		S_2-O_4	22·26± ·37	21·55± ·13	81	67	1·90± ·10	1·53± ·06
	C 19-26	M	...	27·37± ·19	...	76	...	3·68± ·08
		A_2	...	24·24± ·31	...	74	...	2·54± ·11
		A_3	...	25·66± ·25	...	77	...	3·07± ·08
		A_4	...	24·71± ·27	...	71	...	2·60± ·09
		S_1	...	22·40± ·36	...	69	...	1·86± ·11
		S_2-S_3	...	22·58± ·22	...	67	...	1·95± ·10
	A 16-34	M	27·01± ·11	26·49± ·16	75	76	3·85± ·05	2·97± ·06
		A_3	27·10± ·16	25·60± ·43	71	79	3·52± ·04	3·15± ·13
		A_4	26·73± ·11	25·62± ·21	72	80	3·47± ·05	3·13± ·08
		S_1	26·55± ·14	25·47± ·16	73	78	3·40± ·05	2·89± ·06
		S_2	25·69± ·13	24·68± ·20	69	78	2·90± ·06	2·63± ·07
		S_3	24·86± ·19	24·90± ·17	67	76	2·61± ·06	2·54± ·06
		S_4	23·85± ·16	24·45± ·15	63	74	2·21± ·05	2·43± ·05
		S_5	23·33± ·17	...	64	...	2·01± ·06	...
		O_1	22·40± ·14	23·58± ·19	61	69	1·79± ·05	2·16± ·06
		O_2	21·47± ·20	22·10± ·21	59	64	1·59± ·07	1·72± ·05
		O_3	...	21·69± ·22	...	54	...	1·51± ·06
		O_4	...	21·42± ·18	...	50	...	1·33± ·06
		M	28·63± ·08	25·73± ·13	85	84	4·07± ·04	3·54± ·06
		A_2	27·01± ·11	24·25± ·16	86	81	3·69± ·05	2·91± ·09
		A_3	26·56± ·12	24·36± ·19	83	81	3·67± ·06	3·04± ·09
		A_4	26·46± ·12	25·30± ·12	85	82	3·54± ·05	3·25± ·06
		S_1	25·98± ·12	24·63± ·13	82	77	3·30± ·05	2·86± ·05

TABLE II—*contd*

Spacing	Strain	Stems	Length of panicle in cm. 1933	Length of panicle in cm. 1934	Filled grain (per cent) 1933	Filled grain (per cent) 1934	Yield of filled grain per panicle in gm. 1933	Yield of filled grain per panicle in gm. 1934
		S_2 .	25·94± ·10	23·87± ·20	81	73	3·27± ·06	2·47± ·09
		S_3 .	24·80± ·14	24·00± ·16	82	75	2·91± ·07	2·56± ·07
		S_4 .	24·52± ·13	24·00± ·12	78	78	2·69± ·06	2·74± ·06
Wide 18 in. × 18 in.	C 15-10	S_5 .	23·40± ·19	...	75	...	2·31± ·06	...
		O_1 .	23·28± ·16	24·14± ·11	74	69	2·28± ·06	2·50± ·06
		O_2 .	22·22± ·17	23·47± ·14	70	69	1·89± ·07	2·30± ·07
		O_3 .	21·77± ·13	23·99± ·16	55	68	1·39± ·07	2·30± ·09
		O_4 .	...	23·57± ·15	...	64	...	2·07± ·07
		O_5 .	...	22·99± ·10	...	49	...	1·31± ·05
		N_1 .	...	23·31± ·17	...	42	...	1·30± ·06
		M .	...	27·76± ·16	...	79	...	4·05± ·07
		A_3 .	...	26·77± ·29	...	77	...	3·77± ·12
		A_4 .	...	26·73± ·29	...	70	...	3·38± ·12
		S_1 .	...	26·35± ·18	...	74	...	3·54± ·08
		S_2 .	...	25·04± ·26	...	69	...	2·92± ·14
		S_3 .	...	25·87± ·34	...	71	...	3·18± ·12
	C 19-26	S_4 .	...	25·86± ·18	...	68	...	2·99± ·08
		O_1 .	...	24·46± ·18	...	66	...	2·73± ·08
		O_2 .	...	23·47± ·19	...	57	...	1·97± ·09
		O_3 .	...	23·92± ·18	...	59	...	2·10± ·08
		O_4 .	...	23·47± ·18	...	52	...	1·64± ·07
		O_5 .	...	22·62± ·22	...	35	...	1·07± ·07

CORRELATION

Correlations were worked out for the number of tillers (including main stems) and yield of grain per plant. The results, which are shown in Table III, show high positive correlations in all cases between the number of tillers per plant and yield of grain, particularly in the case of wide spacing.

TABLE III

Correlation between the number of tillers and yield of grain per plant

Strain No.	Spacing	Coefficient of correlation	Remarks
A 16-34 . . .	Close . .	+0·7752±0·02801	High
C 19-26 . . .	Do. . .	+0·6243±0·0427	Do.
C 15-10 . . .	Do. . .	+0·7147±0·0338	Do.
A 16-34 . . .	Wide . .	+0·9097±0·0515	Very high
C 19-26 . . .	Do. . .	+0·8658±0·0171	Do.
C 15-10 . . .	Do. . .	+0·8823±0·0154	Do.

Ear development

In the second year of the experiment the development of the ear was studied. The formation of ear primordia in main stems was first observed on the 4th October in A16-34 and on the 12th October in C19-26, which is about 20 and 25 days, respectively, before flowering. In C15-10, ear primordia were not formed till the 20th October, which is about 35 days before flowering, indicating that the formation of ear primordia is not only later in this late pure line, but also that full development of the ear takes a longer time than in earlier-maturing pure lines. When the ear primordia were less than 2 mm. in length, the spikelets with anthers could be seen under the microscope. In Table IV are shown data recorded weekly regarding rates of growth of the ear, together with data regarding the lengths of the panicles and the heights of the plants, the data being obtained by dissecting plants not required in the main experiment.

TABLE IV

Rate of growth of ears and of the rice plant after the formation of ear primordia

	Date of observation (1934)					
A 16-34	4 October	11 October	18 October	25 October	1 November	
Ear in cm.	0·25	3·40	26·20	27·48	27·52	No increase after 1-11-34
Peduncle	..	0·16	3·22	46·20	47·84	Do.
Stem height	Failed to record	14·40	25·50	128·76	131·80	
C 15-10	18 October	25 October	1 November	8 November	15 November	22* November
Ear in cm.	0·13	0·55	7·36	22·84	26·98	27·08
Peduncle	..	..	0·32	0·42	14·60	36·46
Stem height	12·60	18·18	30·50	49·46	84·66	112·44
C 19-26	12 October	19 October	26 October	2 November	9* November	
Ear in cm.	0·37	1·86	21·78	30·40	30·50	
Peduncle	..	0·07	0·62	8·54	25·04	
Stem height	16·38	26·67	60·32	96·98	156·86	

* Flowering date

In the first week after the formation of the ears little increase in their length was observed, but after that period growth was rapid and almost at its

maximum about a week before flowering in all strains under observation. No increase in length took place after flowering. The peduncles in the early stages made very slow growth, but they increased rapidly in length as soon as the ears had attained their maximum growth. It was observed during the growth of the ears that the internodes on the stems elongated. Greater elongation took place in the upper than in the lower internodes and this, together with the elongation of the peduncle, added greatly to the height of the plants after flowering.

The time that elapsed between the first appearance and the full emergence of the ear was about three days in A16-34 and C19-26 and about five days in C15-10. Thus, the rice plant in the early stages of growth appears to utilize its energy mainly in the production of leaves and tillers and later in increasing its height after ears have been fully formed.

Summary

The observations made in the course of the experiments indicate that there is not a definite critical period for tillering in rice under Lower Burma conditions. Nevertheless the period of maximum tiller production in normal planting (close spacing) is up to 30-40 days after transplanting, while in wide planting the period is extended by about a month. Early production of tillers was associated with a large final number of tillers per plant, but was not associated with the date of maturity as the latest maturing pure line, C15-10, produced tillers earlier and also at a higher rate than the other two pure lines in both spacings. It is, therefore, indicated that varietal differences play an important rôle in tillering and as a high positive correlation was found between yield and the final number of ear-bearing tillers (including main stems) which in turn is associated with the early and rapid formation of tillers, it appears that the early and rapid formation of tillers may be an index of high yield capacity in rice.

The conclusions differ somewhat from those arrived at by Ramiah and Narasimham [1936] for Madras, where it was found that there was a definite critical period of tillering which was stated to be two or three weeks before the maximum tillering phase was attained. The maximum tillering phase for Madras appeared to be from three to five weeks after planting according to the duration of the variety, and thereafter there was a reduction in tiller number, due to the death of late or poorly developed tillers.

These differences may be due to differences in soil and climatic conditions, particularly the water supply throughout the growing season.

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IMPROVEMENT OF *TORIA* (*BRASSICA NAPUS* L. VAR. *DICHOTOMA* PRAIN) AND *TARAMIRA* (*ERUCA SATIVA* L.) BY GROUP-BREEDING

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(With Plates XXXIII and XXXIV)

AMONG the various oilseed crops grown in the Punjab, *toria* and *taramira* together occupy nearly 45 per cent of the total area under all the oilseeds. Of these two crops, *toria* is pre-eminently an irrigated crop, grown almost exclusively in the canal colonies of the province, where it occupies an important place in the farm economy due to the fact that its produce is available for sale to the farmer at a time when he badly needs money for paying off land revenue. *Taramira*, on the other hand, is a crop of the drier districts of the province, and is cultivated exclusively as a *barani* (rain-fed) crop in areas which are poorly commanded by irrigation water.

Breeding investigations carried out by Singh [1928], Ali Mohammad, Singh and Alam [1930] in *toria*, and by Alam [1936] in *taramira* have shown that the plants belonging to these two crops are highly self-sterile in nature, setting very few pods and seeds under bag in spite of the facts that the various parts of their flowers are fully formed, their spores are fully functional, and their stigmas and anthers ripen at the same time.

Studies made by Ali Mohammad [1935] on the anthesis and mode of pollination in *toria* have revealed that the plants of this crop depend entirely on insects for the pollination of their flowers, and that the most ardent pollinating agents in this crop are *Andrena ilerda*, *Apis florea* and *Halictus* sp. in the order given. The same species of insects that visit *toria* flowers have been found to visit *taramira* flowers also, with the only difference that in place of *Andrena ilerda*, which is found in largest numbers in *toria* fields, *Apis florea* is the chief pollinating agent in *taramira*.

From a series of self- and cross-fertilization experiments on *toria*, Ali Mohammad [1935] concludes that the plants raised from seeds obtained by crossing attain greater height, produce more branches and form greater number of pods than those raised from seeds obtained by selfing. Alam [1936] arrives at similar conclusions in *taramira*. It is, therefore, apparent that pure-line breeding is not possible in practice for the improvement of these self-sterile crops, and resort has, therefore, to be made to certain methods of group-breeding by which crossing between plants is encouraged, but is restricted to most desirable individuals only. To attain this, the following lines of attack suggest themselves :—

(1) A restricted form of mass-selection, in which the undesirable forms are removed before pollination.

(2) Continuous inbreeding of artificially self-fertilized lines for several generations to eliminate any undesirable characters, which, due to their recessiveness, generally remain masked in an open pollinated crop, and then crossing the best of these in order to regain the vegetative vigour.

(3) Inter-crossing two or more selected plants and their selected progeny under controlled conditions for several generations until the resulting plants are fairly uniform in respect of certain desirable characters.

The efficacy of each of these methods in effecting improvement in the self-sterile crops concerned is being investigated at Lyallpur for the last four years under a scheme sanctioned by the Imperial Council of Agricultural Research for breeding investigations on *Brassica* crops. Their relative efficiency will be correctly known only after the strains produced by these methods have been extensively tested for yield, but on the face of it the last-named method, namely inter-crossing two or more selected plants and their selected progenies under controlled conditions for a number of generations, seems to offer the greatest hope of success. This method, however, involves a large number of plants to be inter-crossed each year and if this is done by hand, the work not only becomes tedious and laborious but also cannot be taken up on an extensive scale so as to make available sufficient quantity of seed, especially during the later stages of the experiment when comparative family trials and other tests have to be carried out. These considerations, therefore, led to the idea of harnessing bees under insect-proof cages for purposes of inter-crossing desirable plants, and in the present paper are outlined various experiments conducted for working out the best technique for doing so and the chief results obtained in them during the past three years.

Review of literature

Though a reference to the literature has not revealed any past record of an attempt having been made by any worker in harnessing bees or any other type of insect for crossing plants of *toria* or *taramira* crops under controlled conditions, there is some evidence available in regard to the utilization of this method for the breeding of other self-sterile crops. Waldron [1908, 1910], Gmelin [1914], Westgate and Coe [1915], Roemer [1916], Pammel and Keynoyer [1917], and Schlecht [1921] have demonstrated that red clover can be cross-pollinated by humble bees and in some cases by honey bees under cages. The experiments made by these workers were undertaken mainly with the object of investigating the pollinating efficiency of humble and honey bees, but the usefulness or otherwise of the bees for controlled pollination for breeding purposes was apparently not studied. No precautions were taken to ensure that the bees were absolutely free from red clover pollen, although an attempt was made by Gmelin and Schlecht to minimize the risk of contamination from this course by using bees taken from flowers other than those of red clover. The first attempt to employ humble bees for critical breeding work with red clover was made by Lindhard [1911, 1921], who usually placed a while family of bees under a cage made of cheese cloth containing the plants intended for crossing. To ensure that the bees were free from red clover pollen, they were placed for a short time under a cage containing *Lotus corniculatus*, before they were allowed access to the clover cage. Williams [1925] also achieved considerable success by introducing clean humble bees into cages made of wire but roofed over with glass, under which the plants of red clover to be

crossed were grown. His method of cleaning the bees consisted of washing them thoroughly with water, before they were let loose in the experimental cage.

Experimental methods and results

(*A*) *Type of bees employed*

From the very start of these experiments attention was focussed on procuring a type of bee that had a colony-forming habit so that the tedious and laborious process of catching individual insects from the open field, as practised by Williams [1925] at Aberystwyth could be dispensed with. For this reason, the most ardent pollinator of *toria* under natural conditions, namely *Andrena ilerda*, which has a solitary habit and does not lend itself to domestication, had to be totally ignored. As certain species of bees belonging to the genus *Apis* are known for their colony-forming habits, and since some of these had been proved to be next best pollinators of *toria*, attempts were made to choose a suitable type of bees from amongst them for these experiments. Of the three important species of *Apis* occurring in the Punjab, namely *Apis dorsata*, *A. florea* and *A. indica*, colony-forming habits of which have been studied by Rahman and Singh [1940], *Apis dorsata* and *A. florea* were considered unsuitable for keeping in modern hives, because the former, besides having a ferocious and vicious temperament, is prone to migrate, while the latter does not live in captivity. These two species, therefore, had to be left out of consideration and the choice ultimately fell on *Apis indica* bees, which were exclusively used for these experiments. This species of bees has a good temperament, is easy to handle, and responds to manipulation very well. Being a good gatherer of honey, it is being bred artificially at the Government Bee Farm, Nagrota and Katrain (Punjab), from which places colonies of this bee were obtained for the present study through the courtesy of Dr Khan A. Rahman, the Entomologist at the Punjab Agricultural College and Research Institute, Lyallpur.

During the first year of the experiment a number of bees separated from a colony of *Apis indica* bees were let loose in cages (described later on) under which *toria* plants to be crossed had been grown, but it was observed that the bees did not settle down and visit flowers but kept flying about near the top of the cage in an attempt to effect escape. Most of them died within one or two days after their confinement, without fulfilling the purpose for which they were meant. The method of harnessing individual bees, as practised by Williams [1925], therefore, did not prove successful at Lyallpur, and for surmounting this difficulty resort had to be made to actually rearing bees inside the cages. In all subsequent experiments, whole colonies of bees reared in Langstroth hives of the pattern shown in Plate XXXIII, figs. 1 and 2 were placed inside the experimental cages, and this method proved very successful. With their home inside the cages the bees soon got used to captivity and began visiting flowers freely in search of nectar, thus bringing about cross-pollination between plants. Since the number of plants growing under a cage was too small to provide enough nectar for the whole colony, it was necessary to replenish the food of the bees with sugar syrup twice a week. By doing so the colony maintained its strength fully throughout the flowering season of the crop and the bees continued working normally, their activity resulting in a high percentage of pod setting, as is evident from the results presented later on.

(*B*) *Trial of cages*

During the first year of the experiment, viz. 1937-38, wooden cages of two kinds, one covered over on all four sides as well as roofed over with wire-gauze having 100 meshes to an inch and the other made of fine voile cloth, were tested with a view to comparing their suitability for protecting *toria* plants and for confining bees used in crossing them. The size of these cages was 10 ft. × 10 ft. × 6 ft. A cage made of voile cloth is shown in Plate XXXIII, fig. 3. The cages were kept in position over the *toria* plants soon after they started blooming. The hives containing the colonies of *Apis indica* bees were also introduced into the cages at that time, one hive being used for each cage. In order to make the cages perfectly insect proof, meticulous care was taken to close all chinks and crevices in between the joints, and also the lower edges of the cages were pitched one to two inches deep into the soil and then banked up on all sides thoroughly with earth. Two cages of each of these types were employed—one cage in each set being used for the introduction of bees and the other kept as control. At harvest time of the crop, data were collected on the height of plants, average number of branches per plant, percentage of pod setting, average number of seeds formed per pod, etc. The comparative data for the experimental as well as control cages (Table I) show that although equally good setting of pods was obtained with the help of bees both in the voile and wire-gauze cages, yet the latter is considered less satisfactory for crossing *toria* plants under controlled conditions, firstly because the wire gauze could not resist the heat of the day and cracked in a very short time, and secondly it could not check, the passage of tiny insects like thrips, etc. through its meshes, which may be a serious source of foreign pollen contamination. On account of these defects, and also because of its prohibitive initial cost, the wire-gauze cage had to be rejected, and during subsequent years only voile-cloth cages were employed for these experiments. The voile cloth is not only completely insect-proof, but also permits more air and light inside the cage than wire gauze, thus helping the plants to attain normal stature without making them much drawn out. The initial cost of voile-cloth cages is also much lower than that of wire-gauze cages, and since such cages do not lack in efficiency in any way, they could be usefully employed by all workers intending to inter-cross plants under controlled conditions with the help of bees.

TABLE I

Growth and fruiting record of toria *plants grown under cages of different types in 1937-38*

Type of cage used and the treatment given	Total number of plants under observation	Average height of plants in inches	Average number of branches per plant	Average No. of: Flowers borne per plant	Average No. of: Pods formed per plant	Percentage of pod setting	Average number of seeds per pod
Voile-cloth cage with bees introduced	20	55·0	6·7	509·4	302·6	59·3	13·7
Voile-cloth cage (control) .	20	63·0	6·3	427·0	73·4	16·1	5·4
Wire-gauze cage with bees introduced	20	50·2	5·0	164·7	110·2	66·9	11·3
Wire-gauze cage (control) .	20	55·0	5·9	344·4	42·2	12·2	3·7

FIG. 1. A Langstroth bee-hive in which *Apis indica* bees were bred

FIG. 2. The component parts of the bee-hiv separately

FIG. 3. An insect-proof cage made of voile cloth, under which hive-bred *Apis indica* bees were harnessed for crossing plants of *toria* and *taramira*

Fig. 1. No. 1. A *toria* plant from the cage to which *Apis indica* bees had been introduced

No. 2. A *toria* plant from the control cage

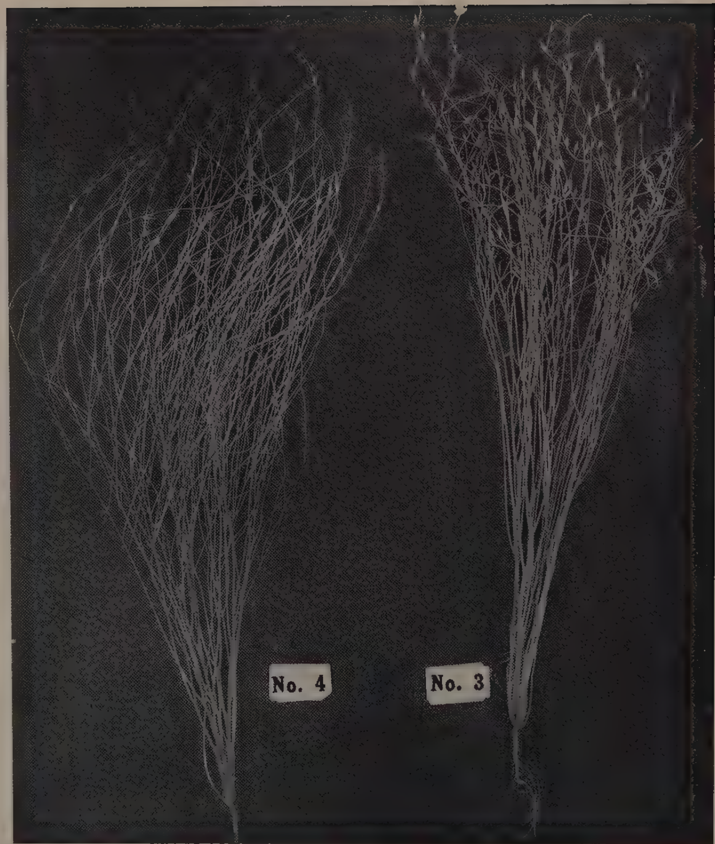

Fig. 2. No. 3. A *taramira* plant from the cage to which *Apis indica* bees had been introduced

No. 4. A *taramira* plant from the control cage

(*C*) *Pod-setting in* toria *and* taramira *with and without the help of bees*

In two subsequent years, viz. 1938-39 and 1939-40, experiments with hive-bred *Apis indica* bees were continued with a view to comparing the pod setting in *toria* and *taramira* plants grown under voile-cloth cages referred to above, to one of which bees were introduced and the other was kept control. Plate XXXIV shows the photographs of *toria* and *taramira* plants taken from both these cages. It is apparent that the plants of both these crops grown under the control cage, to which no bees had been introduced, formed but few pods containing a very few seeds, while the plants grown under the cage containing bees were fully loaded with normal, healthy pods. The actual figures of plant height, number of branches per plant, pod setting percentage, etc. were recorded during two years' experiments on *toria* and one year's experiment on *taramira* and it is apparent from the data presented (Table II) that not only was the pod setting on the plants of both *toria* and *taramira* grown under cages to which artificially bred *Apis indica* bees had been introduced several times higher than that occurring on plants grown under the control cages, but also the pods and seeds formed with the help of bees were much better developed than those obtained in the case of control cages. It may also be stated that the pod and seed setting obtained under controlled conditions with the help of bees used in these experiments compare very favourably with that occurring under natural conditions, in which case, the percentage of pod setting was found to vary between 60 and 85, and the number of normal seeds per pod ranged between 10 and 20. On this account the method of harnessing hive-bred *Apis indica* bees for crossing selected plants and their selected progeny under controlled conditions can be used effectively for the improvement of self-sterile oleiferous Brassica crops concerned.

TABLE II

Growth and fruiting record of toria *and* taramira *plants grown under voile-cloth cages*

(1938-39, 1939-40)

Year	Name of crop and the number of strain	Treatment	Number of plants under observation	Average height of plants in inches	Average number of branches per plant	Average No. of Flowers borne per plant	Average No. of Pods formed per plant	Percentage pod setting	Average number of seeds per pod
1938-39	*Toria* strain P 130	Control (No bees)	15	49·6	9·86	383·39	83·46	21·76	9·49
	Do.	Bee-hive placed in the cage	20	56·15	11·8	751·55	573·20	76·26	13·29
1939-40	Do.	Control (No bees)	25	...	...	406·1	89·0	21·9	8·56
	Do.	Bee-hive placed in the cage	25	58·8	6·28	189·3	148·1	78·2	15·98
	Toria strain P 150	Control (No bees)	25	...	...	571·2	95·1	16·6	7·45
	Do.	Bee-hive placed in the cage	25	56·8	6·44	218·7	184·1	84·2	13·37
	Taramira strain P 2	Control (No bees)	25	48·6	7·3	158·1	27·1	17·1	5·23
	Do.	Bee-hives placed in the cage	25	46·2	6·04	115·0	72·8	63·2	13·62

(*D*) *Freeing the bees of foreign pollen*

For attaining full success in the method of group-breeding described above, it is important that the bees should be completely freed of all foreign pollen before they are introduced to the experimental cages. Williams' method of washing the bees in water and drying them in the sun before letting them in the cages cannot work satisfactorily in the method of group-breeding described here, as in this method whole colonies of bees are required to be introduced to the cages instead of individual bees. Ali Mohammad [1935] has found that the pollen of *toria* remains viable for about seven days after liberation from the anthers. This fact could be made use of in freeing the bees of all foreign pollen sticking to their bodies, the method suggested being captivating the bees in their hives for about a week before they are required to be introduced to the experimental cages. By feeding the bees, during this period of captivity, with sugar syrup their colony strength could be fully maintained. In the case of *taramira* also the period of viability of the pollen is about a week, and the method of shutting up the bees in the hives for that period should prove quite efficacious in this crop also for getting rid of all foreign pollen adhering to the body of the bees.

(*E*) *Utilization of hive-bred bees for increasing yield of* toria

As already mentioned earlier in this paper, seed production in *toria* depends largely on the pollinating activities of three species of insects. It is, therefore, a matter of great concern to the cultivators of this crop to know whether the insects responsible for bringing about cross-pollination are sufficiently numerous in fields to deal effectively with all *toria* crops grown for seeds. Ali Mohammad, Singh and Alam [1930] have found that in certain years the yields of *toria* crop are reduced considerably, owing to insufficiency of insect visitors. Thus, any means adopted for increasing the number of pollinating insects would be of direct benefit and should result in increased yields of this crop.

Several workers have suggested different methods for circumventing the scarcity of insect pollinators in various crops. In fruit trees, Hendrickson [1916], Overholser [1927] and Farrar [1931] suggest supplementing of wild insect pollinators by means of hive bees. In red clover, Fryer and Stenton [quoted by Williams, 1925] advocate that the number of humble bees in any particular locality may be increased by providing the queens with suitable nesting sites and hibernating quarters. Williams [1925] suggests the method of eradicating the natural enemies of *Bombi*, such as mice, shrews and voles, for increasing their number under natural conditions. He also thinks that the number of bees on the clover crop could be increased if plants which are visited by the clover pollinators were cut back when the clover is in flower.

With a view to finding out the scope of utilizing hive-bred *Apis indica* bees for obtaining increased yields of *toria* crop under field conditions, experiments were started in the Oilseeds Breeding Section, Lyallpur, during the year 1938-39. For the purpose of these experiments two large bee-hives of *Apis indica* were placed in a *toria* field of about two acres in area, and the frequency of insect visits per plant in the year 1938-39 and per inflorescence in 1939-40 and percentage of pod setting obtained from this field were compared with those obtained from a normal field of *toria* crop selected at a distance

of four miles from the aforesaid field so as to reduce to minimum the chances of the bred bees reaching that field. Observations on insect visits were made over a period of 15 days during the main flowering season of the crop, and the data on pod setting were recorded for 100 plants selected at random in each field.

It is apparent from the data presented (Table III) that the number of insect visitors per inflorescence as well as per plant per day was roughly three times more in the field where bee-hives had been placed as compared to the normal field in which no bee-hives had been placed. The results also show that with an increase in the frequency of insect visits there was a significant increase of 15·67 per cent and 8·08 per cent in the pod setting during the years 1938-39 and 1939-40, respectively. Since the strain of *toria* grown in the fields under experiment was the same, it is safe to conclude that the increased pod setting in the field where bee-hives had been placed must be the result of increase in the insect population of that field which, as is to be expected, would make the pollination of a larger number of flowers possible than would be the case under conditions where the number of insect pollinator is below the full needs of the crop. The rearing of bees alongside the fields of *toria*, therefore, appears to be a good method of increasing the frequency of insect visitors in the field, which is likely to result in better setting of pods and consequent higher yields of the produce concerned.

TABLE III

Effect of additional bees bred in toria *crop on the number of visits of insect pollinators and pod setting per plant*

(1938-39, 1939-40)

Year	Treatment	Average No. of visits of insect pollinators per plant per day	No. of insect visits expressed as percentage of control	Percentage pod setting	Mean difference of pod setting	Critical difference of pod setting at 1 per cent level	Difference significant or not
1938-39	Two bee-hives placed in the field	161·2	351·7	79·66	+15·67	4·37	Significant
	No bee-hives placed in the field	4·83	100·0	63·99	...	...	...
1939-40	Two bee-hives placed in the field	46·55*	307·06	73·13	+8·08	4·58	Significant
	No bee-hives placed in the field	15·16*	100·0	65·05	...	...	...

*These figures represent visits per inflorescence.

SUMMARY

The details of a new method of group-breeding, in which *Apis indica* bees could be harnessed under insect-proof cages for crossing selected plants of *toria* (*Brassica napus* L. var. *dichotoma*, Prain) and *taramira* (*Eruca sativa* L.) with a view to improving them is described.

Of the two types of cages experimented with, the best results were obtained by using cages made of very fine voile cloth. Wire-gauze cages proved unsuitable for the purpose, on account of their shorter life, high initial cost, and inability to check the passage of thrips, etc. which may be a serious source of foreign pollen contamination.

Introduction of individual *Apis indica* bees to the cages did not prove successful in effectively crossing the *toria* and *taramira* plants. However, by actually rearing colonies of bees inside the cages in Langstroth hives the bees worked normally, their activity resulting in as good pod and seed setting as is obtained under open field conditions.

As for the method of freeing bees of foreign pollen before they are introduced to the experimental cages, it is suggested that the bees should be kept in captivity inside their hives for about a week, so that all pollen sticking to their bodies loses its viability and is thus disabled to viciate the choice plants intended to be inter-crossed with the help of bees.

Data are also presented to show that the insects responsible for bringing about cross-pollination in *toria* under natural conditions are below the full needs of the crop, and that the pod setting and consequently the yield of this crop could be considerably enhanced by supplementing the insect population of *toria* fields with hive-bred *Apis indica* bees.

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SOOTY-BLOTCH AND FLY-SPECK OF APPLE FRUIT IN KUMAUN

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THE sooty-blotch and fly-speck disease is caused by *Leptothyrium pomi* (Mont. and Fr.) Sacc. and appears commonly on light-coloured and late varieties of apple, such as Claygate Pearmain, Hawthorn Greening, Rymer, Jonathan, Delicious and Newton Pippin. A strain of the same fungus infects pear fruits. It is known to occur in England, Canada, the United States of America, New Zealand, and Australia, in fact in all apple-growing countries. Macoun [1907] reported this disease from Canada. In England it was first recorded by Salmon [1910]. In India it was recognized first at Ramgarh, Kumaun [Butler, 1918] and again in the same locality [Butler, 1920]. In Chaubattia it was first recorded by the author in 1934.

The normal growth of the fruits affected with the disease is not checked. But they become badly blemished and thus their market value is reduced. The diseased fruits fetch only half the price of clean fruits.

The disease is known as sooty-blotch and fly-speck. The blotches are irregular in outline to roughly circular. At first the colour is pale brown, but later on it becomes sooty brown or black. Single spots measure $\frac{1}{4}$-$\frac{1}{2}$ in. in diameter ; often several lesions coalesce, covering the apple as if with soot. Spots become radiating or star-like, composed of a thin felt of dark brown interwoven threads which are seen with the naked eye or better with a hand lens. Fly-speck is simply a different symptom of the disease. The two are found in the same situation and under similar conditions except that fly-speck develops later than sooty-blotch. In fly-speck a number of small shiny dots appear on the surface of the apple, the specks closely resembling those made by a fly. Both sooty-blotch and fly-speck are superficial and are hardly skin deep.

The sooty-blotch spots are composed of the fungus *Leptothyrium pomi* (Mont. and Fr.) Sacc. The black dots of fly-speck are the sclerotial bodies of the fungus, which presumably enable it to overwinter. In late spring each sclerotial body undergoes certain developmental changes and forms a pycnidium. Conidia develop within the pycnidia and start fresh infections in summer. Apparently infection does not occur before July. Pieces of the mycelium of the fungus which form the blotches become swollen and break off, are carried by water or otherwise to other fruits, and start fresh infections. The disease increases on fruits in storage.

Control measures

Three methods of control, namely by spraying, by thinning the fruit and by washing fruits with chemicals, were carried out.

Spraying

Butler [1918] carried out spraying experiments in Kumaun orchards and found that trees sprayed with lime-sulphur showed less disease than unsprayed ones. To control the damage, a spraying expriment with home–made lime-sulphur wash and Avon's colloidal sulphur was started in 1938. The experiment was on the lines of work done in U. S. A., described by Hesler and Whetzel [1924]. The prepared concentrated lime-sulphur tested 32° Baume, specific gravity 1·283; and each gallon of this concentrated solution was diluted by adding 40 gallons of water. The lime-sulphur was prepared in the usual manner as given by Butler [1918]. Avon's colloidal sulphur was prepared by mixing 5 lb. of the concentrated commercial preparation with 100 gallons of water. Twenty-one trees of apple of each of two varieties, viz. Claygate Pearmain and Esopus Spitzenberg of the same size and age were selected in two separate blocks of the orchard, named N and E respectively. Each block was divided into seven sub-blocks, each sub-block having three trees, two for the treatments and one as control. The two treatments together with controls were randomized in each sub-block.

In one block (block E) the spraying was done on the following dates :—

28 March 1938 (open cluster stage)
11 April 1938 (petal fall stage)
19 April 1938 (fruit formation)
2 August 1938 (when the fruits were mature)

In the second block (block N) they were done a day later each time. In the third week of August 1938 when the fruits were ready for picking a record of the infected and uninfected fruits was taken for each individual tree under experimentation.

The analysis of variance was worked out and is given in Tables I and II. It is concluded that in block N the treatment A=B, B=C and A>C, while in block E the treatment A>B>C.

The cost of spraying per tree comes to about 12 annas and is certainly too much for an orchardist to spend, and therefore this method of controlling the disease does not seem to be feasible.

TABLE I

Comparison of different treatments in block E

No.		Mean percentage of good fruits			General mean	Standard error of difference	Critical differences for significance	Whether significant by 'z' test
		A Lime-sulphur	B Avon's colloidal sulphur	C Unsprayed (control)				
1	Per treatment	58·28	19·22	0·45				
2	Percentage on general mean	224·32	73·97	173·97	25·98	8·04	17·51916	Yes, P=0·01
3	Percentage on control	129·51	4271·11	100·00				

TABLE II

Comparison of different treatments in block N

No.		Mean percentage of good fruits A Lime-sulphur	B Avon's colloidal sulphur	C Unsprayed (control)	General mean	Standard error of difference	Critical difference for significance	Whether significant by 'z' test
1	Per treatment .	9·88	5·64	0·70				
2	Percentage on general mean	182·96	104·44	12·96	5·40	2·87	6·39436	Yes, $P=0{\cdot}01$
3	Percentage on control	1268·57	805·71	100·00				

Thinning the fruit

Thinning is known to help in the production of a better class of fruits, both as regards their size and colour. Fruits from thinned trees fetch a better price in the market. There is also not much difference in gross weight of fruits obtained from thinned and unthinned trees. The experiments carried out at Chaubattia by the Horticulturist fully substantiate the above statements.

In 1938 thinning experiments were laid out by the Horticulturist at Rajkhet orchard (Bhowali). The thinning was based on the volume of the tree and the fruits retained with different treatments were according to unit volume of the tree. There were three treatments, namely (*i*) one and a half fruits retained per cubic foot of the volume of the tree, (*ii*) two fruits retained per cubic foot of the volume of the tree, and (*iii*) unthinned (control) with 3·3 fruits per cubic foot of the volume of the tree. The horticulturist carried out his experiment on Rymer (a late variety). The purpose of the experiment was to find out whether thinning has any effect in decreasing the incidence of the disease. The fruits harvested from each treatment were graded according to their size in five grades with diameter of (*a*) $3\frac{1}{4}$ in. and above, (*b*) between 3 in. and $3\frac{1}{8}$ in., (*c*) between $2\frac{7}{8}$ in. and $2\frac{3}{4}$ in. and (*d*) $2\frac{5}{8}$ in. and below. After this, fruits of each size grade were further graded into four groups, depending on the percentage infection of the sooty-blotch and fly-speck under each size grade, viz. (*a*) between 50 and 70 per cent, (*b*) between 30 and 50 per cent, (*c*) between 10 and 30 per cent, and (*d*) below 10 per cent. From the size grading the total surface area of the fruits from each individual tree was calculated and from the infection grading of size and the size grades the total infected area of individual fruit was obtained. The percentage of the infected surface area to the total surface area formed the criterion for judging the effect of thinning on the incidence of sooty-blotch. Table III summarizes the results obtained. It shows that the most severely thinned trees ($1\frac{1}{2}$ fruit retained per cubic foot of the volume of the tree) had significantly less incidence of the disease than unthinned (control) having 3·3 fruits per cubic foot of the volume of the tree. The lesser degree of thinning (two fruits retained per cubic foot of the volume of the tree) did not show any significant difference from either the unthinned (control) or the most

severely thinned ($1\frac{1}{2}$ fruit retained per cubic foot of the volume of the tree). Thus it appears that the incidence of sooty-blotch disease is minimum only under conditions of severest thinning, namely $1\frac{1}{2}$ fruit retained per cubic foot of the volume of the tree.

Table III

Effect of thinning of apple fruits on percentage of infection of sooty-blotch

No.		Mean percentage infection			General mean	Standard error of difference	Critical difference for significance	Whether significant by 'z' test
		One and a half fruits per cubic foot of the volume of the tree	Two fruits per cubic foot of the volume of the tree	Unthinned (control) 3·3 fruits per cubic foot of the volume of the tree				
1	Per treatment	11·9	13·9	15·3	13·7	1·37	3·05	Yes, $P=0·05$
2	Percentage on general mean	87·00	101·5	111·7				
3	Percentage on control	77·8	90·8	100				

Chemical treatment

Washing the apple fruits with bleaching powder 5 per cent was recommended by Bottomley [1935] and Wormald [1936]. Forty-eight apple fruits of one variety (Sturmer Pippin) of the same maturity, which were already affected with sooty-blotch and fly-speck, were used. The infected area of the fruits was about 20 per cent. These were divided into six lots of eight fruits each.

Six treatments each replicated eight times were carried out : (1) control (untreated) ; (2) fruits washed with tap water, the sooty-blotch removed and dried with a cloth ; (3) fruits dipped in bleaching powder solution (5 per cent) for one minute, exposed to the air for ten minutes, washed with tap water, sooty-blotch removed and dried with a cloth ; (4) fruits dipped in a solution of sodium chlorate (1 per cent) for one minute, exposed to air for ten minutes, washed with tap water to remove the sooty-blotch, and dried with a cloth ; (5) fruits dipped in 2 per cent sodium chlorate and then proceeded with as in treatment (4) ; (6) fruits dipped in 3 per cent sodium chlorate solution and then proceeded with as in treatment (4).

The fruits of one treatment were kept in one tray and each fruit was kept apart from the other. All the six trays were placed in the fruit godown on 8 September 1939. The fruits were examined periodically up to 19 March 1940. From Table IV it will be seen that there was an increase in the intensity of both sooty-blotch and fly-speck in treatments (1) (untreated control), (2) (washed with water), (4) and (5) (treated with sodium chlorate 1 and 2 per cent respectively). The fruits treated with bleaching powder 5 per cent (treatment 3) and those treated with 3 per cent sodium chlorate (treatment 4), showed very slight increase in the intensity of either sooty-blotch or fly-speck,

Table IV

Observations regarding the control of sooty-blotch and fly-speck disease of apple fruits under various treatments

Fly-speck (1) below 10 numbered
(2) 10—15 +
(3) 16—20 ++
(4) 21—30 +++
(5) beyond 30 ++++

No.	Treatment		8-9-39	19-3-40
I	Untreated control	Average percentage of sooty-blotch	20	85
		Average incidence of fly-speck	+	++++
II	Washed with water only	Average percentage of sooty-blotch	0	50
		Average incidence of fly-speck	++	+++
III	Dipped in 5 per cent bleaching powder	Average percentage of sooty-blotch	0	0
		Average incidence of fly-speck	7	++
IV	Dipped in 1 per cent sodium chlorate	Average percentage of sooty-blotch	0	60
		Average incidence of fly-speck	+++	++++
V	Dipped in 2 per cent sodium chlorate	Average percentage of sooty-blotch	0	40
		Average incidence of fly-speck	++	++++
VI	Dipped in 3 per cent sodium chlorate	Average percentage of sooty-blotch	0	0
		Average incidence of fly-speck	++	+++

Discussion

Sooty-blotch and fly-speck of apples is a serious disease in Kumaun. Although it does not affect the flesh of apples, it causes disfigurement and thereby reduces the market value by nearly half. Of the three different treatments discussed in the paper, thinning of fruits and use of 5 per cent bleaching powder solution and 3 per cent sodium chlorate solution in washing the fruits are cheap and practicable. Thinning does not affect the gross yield of the crop, but reduces the incidence of the disease.

Summary

1. Sooty-blotch and fly-speck of apples is caused by *Leptothyrium pomi* (Mont. and Fr.) Sacc. It causes blemishes in the fruit and reduces its market value.

2. The blotches caused by sooty-blotch are irregular in outline, tending to be circular. The colour at first is pale, but later on it becomes sooty brown or black. Single spots measure $\frac{1}{4}$-$\frac{1}{2}$ in. in diameter. They often coalesce, covering the apple. Spots exhibit a radiating structure composed of a thin felt of dark brown interwoven threads which can be seen with the naked eye or with a hand lens.

3. Fly-speck is a different symptom of the same disease. In this a number of shiny small dots appear on the surface of the apple. Both sooty-blotch and fly-speck are superficial in nature.

4. The sooty-blotch spots are composed of the hyphae of the fungus, *Leptothyrium pomi* (Mont. and Fr.) Sacc. The dots of fly-speck are sclerotial bodies of the same fungus.

5. It is not known how the fungus hibernates in winter. It has been suggested that it hibernates on the apple twigs presumably as sclerotial bodies. These sclerotial bodies, after undergoing developmental changes, give rise to pycnidia from which pycnospores are discharged in summer and cause fresh infection of fruits. At times pieces of the mycelium of the fungus get broken off and are carried by the rains or otherwise to other fruits.

6. The methods of controlling the disease consist of : (*i*) spraying, (*ii*) thinning the fruits, and (*iii*) chemical treatment of fruits intended for storage.

(*i*) *Spraying*.—By spraying the fruits with either lime-sulphur or Avon's colloidal sulphur the disease can be successfully controlled. The method is costly and tedious.

(*ii*) *Thinning the fruits*.—Thinning of the fruits (1½ fruits retained per cubic foot of the volume of the tree) appreciably decreases the incidence of the disease. There was not much difference in gross weight of fruits obtained from thinned and unthinned trees. Fruits from thinned trees were bigger in size and more coloured.

(*iii*) *Chemical treatment*.—Washing the fruits with either a 5 per cent solution of bleaching powder or a 3 per cent solution of sodium chlorate controls the disease in storage.

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STUDIES ON THE CHEMICAL CONSTITUENTS OF INDIAN LATERITIC AND RED SOILS

II. INFLUENCES OF FREE SESQUIOXIDES AND FREE SILICA COMPONENTS OF INDIAN RED SOILS ON THE BUFFER CURVES OF THE SOILS

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(With five text-figures)

IN a recent paper Raychaudhuri and Sulaiman [1940] have discussed the importance of determining the percentages of free sesquioxides and of free silica in Indian red soils on profile basis, which would indicate the manner in which the amorphous product of weathering has been washed down the soil profiles. They have determined the percentages of free sesquioxide components by following the method devised by Hardy [1931], later on modified by Hardy and Rodrigues [1939], and also by following the method devised by Drosdoff and Truog [1935]. The method of determining free sesquioxides by the latter workers, subsequently modified by Truog and co-workers [1937] appears to be specially interesting, in that it enables us to separate the amorphous products of weathering, viz. free silica, free alumina, and free iron oxides, from the crystalline products of weathering and thus to study separately the physico-chemical properties of the crystalline product of weathering which represents really the active material of the soil. It was felt desirable to compare the base-exchange properties of the residue left after treatment of the soils by the Truog's reagent for the separation of the sesquioxide components. In the work embodied in the present paper a comparison has been made of the buffer curves of some profile samples of Indian red soils and of the residues of the same soils after treatment by the Truog's reagent. Hardy [1931] has postulated that iron oxide absorbs alizarin sulphonate dye in the non-ignited state, whilst on ignition it loses its power of absorbing the dye. On the other hand, alumina gel in the non-ignited state possesses no power of absorbing alizarin sulphonte, whilst in the ignited state it acquires the power of absorbing the dye. It was felt desirable to compare, in this connection, the buffer curves of ignited and non-ignited gels of silica, alumina and iron oxide.

EXPERIMENTAL

Preparation of inorganic gels

(*a*) *Silica gel*.—It was prepared by hydrolysing pure silicon tetrachloride in a large volume of water and then adding an excess of ammonia. The gel obtained was at first dialysed in a parchment bag immersed in distilled water. It was then electrodialysed in a 220-volt current for a long time with a constant

flow of distilled water until there was no trace of ammonia and chlorine in the cathode and anode chambers respectively. The presence of ammonia was tested with the help of Nessler's reagent and that of chlorine by means of a solution of silver nitrate. The electrodialysed gel was then filtered and dried in an electric oven kept at a constant temperature of 34°C. until the weight of dry gel was found constant.

(*b*) *Aluminium hydroxide gel.*—Ammonia was added in excess to a solution of pure aluminium chloride in water. The gel of aluminium hedroxide was then electrodialysed in exactly the same way as before, until ther was no trace of chlorine and ammonia. The electrodialysed gel after filtration was dried as before.

(*c*) *Ferric hydroxide gel.*—Excess of ammonia was added to a solution of pure ferric chloride in water. The jelly-like mass so obtained was electrodialysed, filtered and dried to constant weight as in the previous cases.

Electrodialysis of inorganic gels.—The gels were electrodialysed in a three-chambered electrodialysis vessel devised by Mattson [1926]. The substances were kept in the middle chamber and electrodialysis was carried out until the liquid at the cathode was neutral.

Ignition of the inorganic gels.—The ignition of the inorganic gels was carried out in a thermo-regulated electric muffle furnace at 750°C. for 15 minutes.

Determination of buffer curves.—For the determination of buffer courves the procedure devised by Schoeld [1933] was used [Raychaudhuri and Nandy-majumdar, 1940].

Sodium sulphide-oxalic acid treatment for the removal of free iron and aluminium oxides and colloidal, i.e. free silica. [*Truog et al., 1937*].—5 gm. of soil passing through a 100-mesh sieve were placed in a litre beaker and 25 c.c. of 10 per cent hydrogen peroxide were added. The beaker was covered, allowed to stand for about two hours, heated for several hours at a lower temperature and then at a higher temperature without the cover glass until the contents were dry. This treatment was repeated until the action ceased when hydrogen peroxide was added. 650 c.c. of water and 5 c.c. of 20 per cent sodium sulphide solution were added, the mixture was boiled for five minutes and 10 gm. of ammonium chloride were added. By means of a low flame the suspension was kept at 80°-90°C. until it was ready for centrifuging. Oxalic acid solution was added immediately in small quantities with vigorous stirring until *p*H 6 was reached using bromo-thymol blue on a spot plate. 10 c.c. of 20 per cent sodium sulphide solution were then added with stirring. Oxalic acid was then added rapidly until *p*H 7 was again reached, then slowly from *p*H 7 to *p*H 6, and then rapidly to *p*H 3·5, using bromo-phenol blue on a spot plate. After stirring and allowing to stand for a few minutes until the black sulphides had dissolved, the *p*H was again brought back to 7 with 2 *N* ammonia solution, when ferrous sulphide and ammonium sulphide were formed ; 5 c.c. of 20 per cent sodium sulphide solution were then added, and oxalic acid was added rapidly until *p*H 7 was again reached and then slowly from *p*H 7 to *p*H 6 and then more rapidly to *p*H 3·5. This treatment was repeated three to four times. The suspension was digested at 80°-90°C. until coagulation took place which was then transferred to centrifuge tubes, allowed to stand for a few minutes, the supernatant liquid was collected by decantation after centrifuging and the residue was

washed twice with $0 \cdot 001N$ hydrochloric acid containing 5 per cent sodium chloride by centrifuging. The supernatant liquid together with the washings was heated on a hot plate until the clay settled, the clear liquid was then siphoned off and the clay was washed with $0 \cdot 001N$ hydrochloric acid containing 2 per cent sodium chloride. The supernatant liquid together with the washings was evaporated to dryness and the residue was dehydrated at 110°C. for two to three hours. The residue was treated with 25 c.c. of 6 N hydrochloric acid, digested on a hot plate for a few minutes and then diluted to about 50 c.c. The silica was filtered off and was determined in the usual way.

In order to remove sulphur from the residue, it was washed twice with 95 per cent ethyl alcohol to remove water, then three times with a mixture of one volume of carbon disulphide and 2 volumes of 95 per cent ethyl alcohol and finally four to five times with 95 per cent ethyl alcohol to remove carbon disulphide.

Determination of percentages of free alumina and free iron oxide.—The presence of free alumina and free iron oxide in soil was determined by following essentially the alizarin-adsorption method of Hardy and Rodrigues [1939].

For the determination of free alumina two portions, each of mass 1 gm., of air-dried soil passing through a 100-mesh sieve, were taken in silica crucibles covered with lids, and were ignited in a thermo-regulated electric muffle furnace at 750°C. for 15 minutes. After cooling, the ignited material was transferred to large boiling tubes, one containing 20 c.c. of $0 \cdot 5$ per cent solution of sodium alizarin sulphonate in boric alcohol, the other containing 20 c.c. of boric alcohol alone. Both tubes were fitted with Hopkin's reflux condensers and heated in a gently boiling water-bath for 10 minutes. After settling, the supernatant liquid in each tube was decanted into a Buchner funnel containing a pad of filter paper pulp and filtered by suction into a filtering flask. In each case the soil material in the tube was treated with 20 c.c. boric alcohol, boiled and the whole suspension was poured into the funnel and filtered by suction. Excess of dyestuff was next removed in one case by washing with several portions of boiling distilled water until the filtrate was quite colourless. The duplicate (' blank ') treatment was carried out in exactly the same manner, the material being given the same number of washings.

The adsorbed dye-stuff from the stained material was extracted by treatment with boiling saturated aqueous sodium oxalate-oxalic acid solution at pH $3 \cdot 8$. The paper pad and the stained material were returned to the boiling tubes, adhering particles being washed off the funnel with oxalate solution. The volume was made up to about 30 c.c., and the mixture was boiled, settled and decanted into the funnel containing a fresh filter paper pulp. The washing was repeated several times with small quantity of oxalate solution and finally the volume was brought to a definite amount for the purpose of colorimetric comparison with a standard. The concentration of the dye-stuff in the extract was measured in a Duboscq colorimetre against a standard.

Suitable alizarin standards were prepared by diluting $0 \cdot 25$-2 c.c. of the original $0 \cdot 5$ per cent solution of alizarin Red-S with appropriate volume of the ' blank ' oxalate extract of the unstained material ; this corrected the colour caused by iron and organic compounds soluble in the oxalate solution.

For the determination of free iron oxide exactly the same procedure with fresh unignited soil was followed, the blank correction being applied in each case.

RESULTS AND DISCUSSION

Buffer curves of electrodialysed gels

Buffer curves of the following substances have been studied :—

(1) Ignited and non-ignited electrodialysed iron oxide gel,
(2) Ignited and non-ignited electrodialysed alumina gel, and
(3) Ignited and non-ignited electrodialysed silica gel.

The results are shown in Table I, and graphically in Fig. 1.

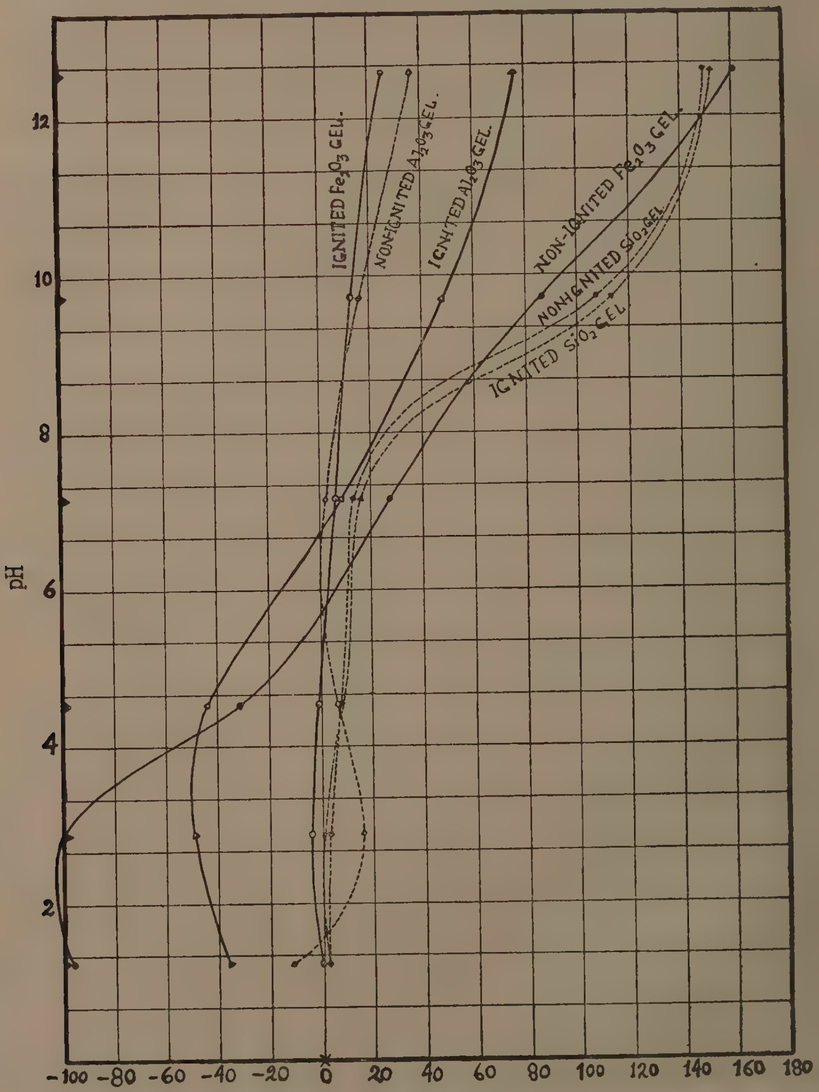

FIG. 1. Milli-equivalents of base taken up by 200 gm. of oven-dry material

TABLE I

Uptake of base with non-ignited and ignited electrodialysed gels of iron oxide, alumina and silica

pH	Iron oxide gel		Alumina gel		Silica gel	
	Non-ignited	Ignited	Non-ignited	Ignited	Non-ignited	Ignited
1·3	—96·7	0	—11·1	—36·3	+2·0	+2·0
2·9	—100·9	—4·0	—16·5	—48·7	2·0	1·0
4·6	—30·8	—1·0	—5·4	—42·7	6·9	7·0
7·1	+27·1	+5·8	+1·3	+7·5	12·7	15·8
9·8	86·3	12·5	16·8	47·6	106·9	112·7
12·5	160·8	25·0	36·3	75·9	147·8	151·0

The buffer curves of iron oxide ignited and fresh are in general agreement with the conclusions made by Hardy [1931] that ignited ferric oxide is much less active than the same substance in the non-ignited state. Actually the base-combining capacity of the ignited ferric oxide gel is almost nil throughout the *p*H range studied.

Also the relative base-combining capacities of electrodialysed alumina and ignited alumina gels show the same agreement with the Hardy's view in that the base-combining capacity of ordinary alumina gel is much less than that of ignited gel. The buffer curves of ordinary electrodialysed silica gel and of ignited silica gel are on the other hand almost coincident. In the latter case no negative adsorption is at all found which may be explained as being due to its strong acidic nature.

A peculiar behaviour was noticed in the buffer curves in Fig. 1 in that the base-combining capacity at *p*H 2·9 is higher than that at *p*H 1·3. This is contrary to usual expectations and may be explained as being due to the amphoteric nature of the sesquioxides. The buffer curves of silica gels show strong inflexion at *p*H 9·8. It might appear, therefore, that the inflexions at *p*H 9·8 observed with ordinary soils might be due to the presence of free silica. This point, however, requires thorough investigation. A possible explanation of this buffering action of silica gels at *p*H 9·8 might be due to the acidic nature of silica which acts with bases at high *p*H values.

Some difficulty was experienced in the titrations of the supernatant liquids obtained with ordinary electrodialysed ferric hydroxide gels and both ordinary and ignited electrodialysed gels of alumina. At low *p*H values some turbidity of the supernatant liquid was observed with both ignited and non-ignited alumina gels indicating the formation of precipitates. Actually in the case of electrodialysed iron oxide gel, formation of definite precipitates took place at *p*H 1·3 and 2·9 and a fairly deep brownish colouration at alkaline *p*H was observed. It is likely that the formation of these precipitates have a great deal to do with the peculiar behaviour of these substances in that the base-combining capacity at *p*H 2·9 is higher than that at *p*H 1·3.

Influences of free alumina on the inflexion of buffer curves

Since aluminium ion tends to pass into colloidal state at *p*H 4·6 [Britton, 1929], it was thought that free alumina might be responsible for the buffer capacities at this *p*H value. The significance of the inflexions of the buffer curves at *p*H 2·9, 4·6 and 9·8 have been discussed by Raychaudhuri and Nandymajumdar [1940]. It was thought desirable to examine whether the percentages of free alumina have any influence on the inflexions of the buffer curves at *p*H 4·6.

Table II shows the percentages of free iron oxide, free alumina and free silica of the same profiles, and also the buffer values (dB/dpH) of the soil samples at *p*H 4·6 (Fig. 2). The percentages of free iron oxide and free alumina have been determined by following the method of Hardy and Rodrigues [1939], whilst the percentages of free silica have been obtained by following the method of Truog, *et al.* [1937].

TABLE II

Percentages of free iron oxides, free alumina, and free silica and dB/dp*H values at* p*H 4·6*

Locality	Soil No.	Depth	Iron oxide	Alumina	Silica	dB/dpH*
Hathwara, Manbhum, Bihar	81p	0—1 ft. 6 in. . .	4·29	0·14	nd.	0·00066
	82p	1 ft. 6 in.—2 ft. 3 in. .	3·46	..	nd.	0·0014
	83p	2 ft. 3 in.—3 ft. 6 in. .	3·55	0·13	nd.	0·0017
	84p	3 ft. 6 in.—4 ft. 11 in.	4·47	..	nd.	0·0013
	85p	4 ft. 11 in.—below .	2·35	..	0·55	0·0011
Lalgarh, Midnapur, Bengal	112p	0—4 in. . . .	4·41	0·20	nd.	0·0013
	113p	4 in.—3 ft. 4 in. .	2·14	0·70	0·50	0·0010
	114p	3 ft. 4 in.—4 ft. . .	1·57	0·15	nd.	0·0006
	115p	7 ft.—8 ft. . . .	nd.	0·29	nd.	0·00033
Cheerapunji, Khasi hills, Assam	124p	0—7 in. . . .	1·24	0·09	0·37	0·00025
	125p	7 in.—10 in. . .	1·16	0·75	nd.	0·0033
	126p	10 in. —4 ft. . .	3·00	0·36	nd.	0·0030
	127p	10 ft.—below . .	0·55	..	nd.	0·0025

*These values of dB/dpH have been obtained from the work of S. P. Raychaudhuri and P. K. Basuraychaudhuri, which is being communicated for publication in the *Indian Journal of Agricultural Science.*

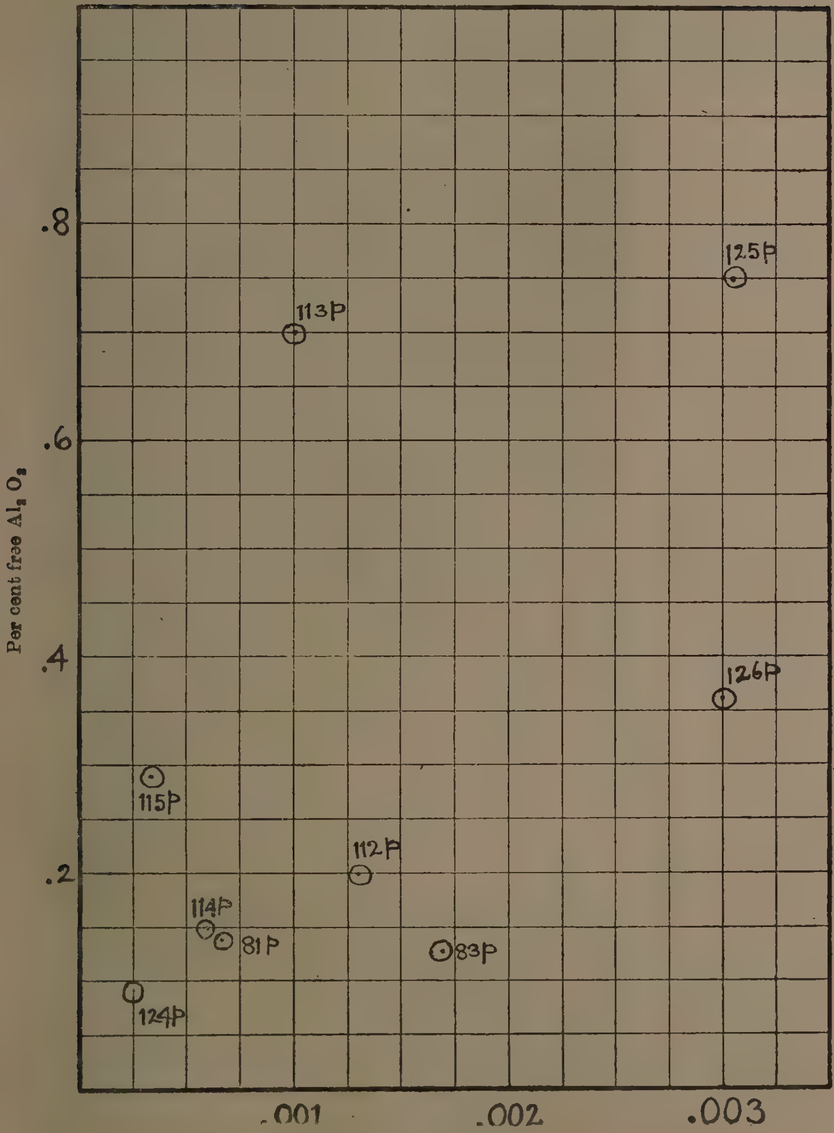

FIG. 2. dB/dpH at pH 4·6

Fig. 2 shows that there is apparently no definite correlation of the buffer values with the percentages of free alumina.

Effect of removal of free silica, alumina, and iron oxide on buffer curves

Three soils were chosen for this experiment (85p, 113p and 124p). The amorphous products of weathering, mainly the free silica, free alumina and free

iron oxide in these soils, were removed by Truog's treatment, and the buffer curves of the residues were drawn with lime buffers. The results are given in Table III where the corresponding data of the ordinary air-dry soil are also included.

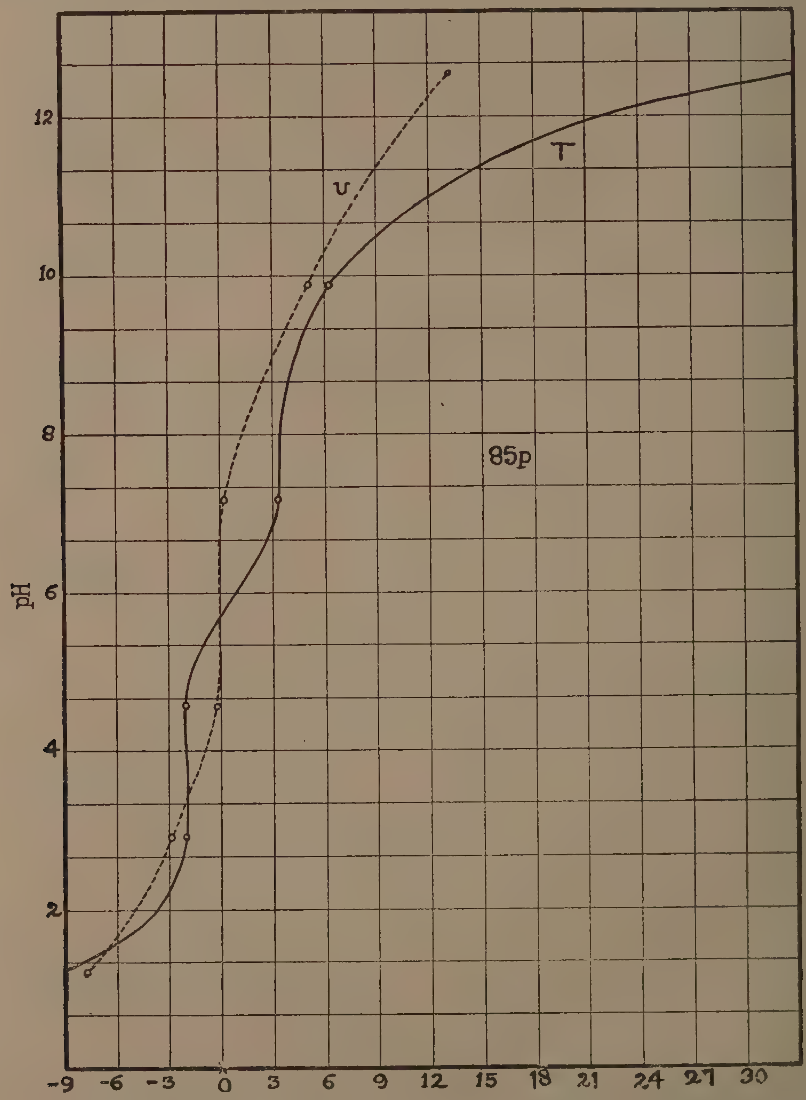

FIG. 3. Milli-equivalents of base taken up by 100 gm. of oven-dry soil

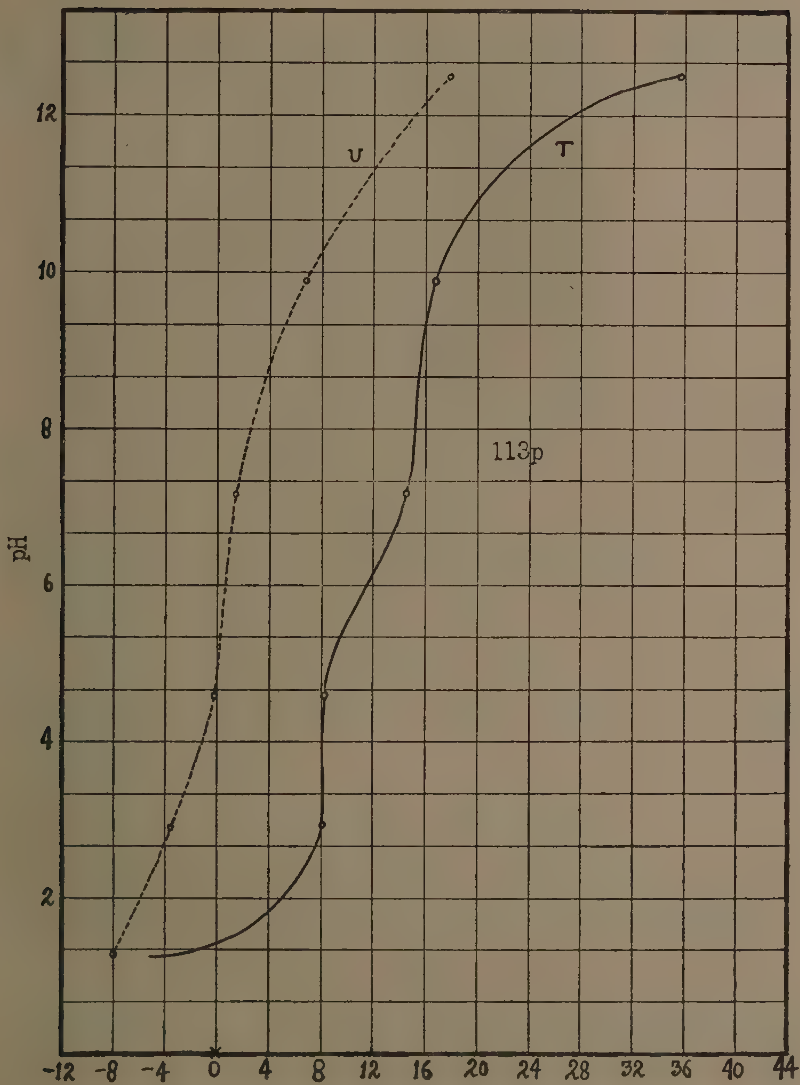

FIG. 4. Milli-equivalents of base taken up by 100 gm. of oven-dry soil

Figs. 3, 4 and 5 show respectively the buffer curves of the soils 85p, 113p and 124p before and after Truog's treatment. In the graphs the buffer curves of the untreated soils have been described as 'U', whilst the buffer curves of treated soils as 'T'. It will be seen that, in accordance with ordinary expectations, the buffer curves of treated soils are flatter than those

of the untreated ones, indicating that the removal of the gels of silica, alumina and iron oxide concentrate the residue with respect to active base-combining materials, so that a certain weight of the residue would possess higher base-combining capacities than the same weight of untreated soil. It will be seen also that all the treated soils show somewhat buffering action at *p*H 7·1 and that the untreated soils 85p and 113p show strong buffering action at *p*H 2·9.

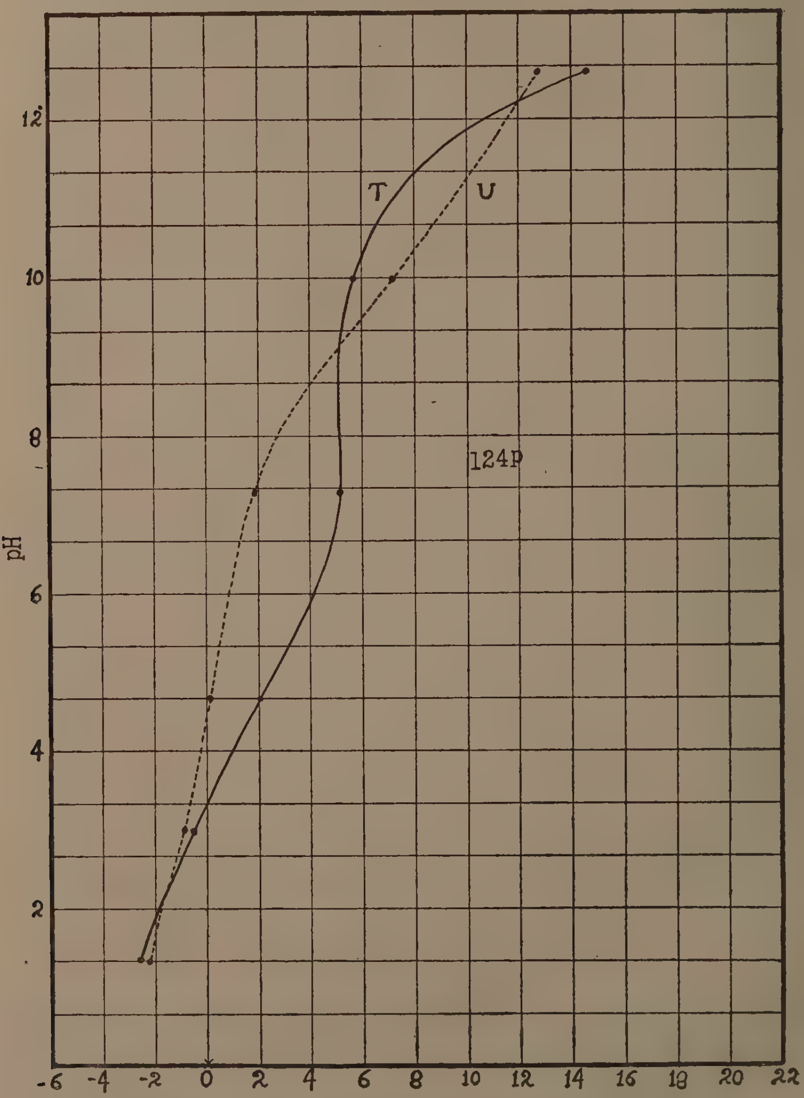

FIG. 5. Milli-equivalents of base taken up by 100 gm. of oven-dry soil

TABLE III

Uptake of base in milliequivalent by 100 gm. of soil in the ordinary air-dry conditions and after removal of free silica, free alumina, and free iron oxide by Truog's method

pH	85p		113p		124p	
	Un-treated	Truog-treated	Un-treated	Truog-treated	Un-treated	Truog-treated
1·3	—7·6	—9·7	—8·0	—5·1	—2·2	—2·5
2·9	—2·9	—2·0	—3·7	+8·2	—0·82	—0·61
4·6	—0·71	—2·0	—0·66	8·2	+0·18	+2·0
7·1	+0·69	+3·3	+1·3	14·5	1·8	5·0
9·8	5·1	6·3	6·9	16·8	6·9	5·5
12·5	13·4	34·3	17·6	35·6	12·5	14·3

SUMMARY

1. Buffer curves of the following substances have been studied :—

(*i*) Ignited and non-ignited electrodialysed iron oxide gel,

(*ii*) Ignited and non-ignited electrodialysed alumina gel, and

(*iii*) Ignited and non-ignited electrodialysed silica gel.

The buffer curve of ignited iron oxide gel is much steeper than that of the non-ignited one. Actually the base-combining capacity of ignited ferric oxide gel is almost nil throughout the *p*H ranges studied. On the other hand, ignited alumina gel possesses much more buffer capacity than the non-ignited one.

The buffer curves of ordinary electrodialysed silica gel and of ignited silica gel are almost coincident.

2. There is apparently no regular variation of the buffer values of soils studied, at *p*H 4·6, with the percentages of free alumina.

3. Three soil samples were freed from the amorphous products of weathering, viz. free silica, free alumina and free iron oxide, and the buffer curves of the residues were compared with those of the original soils. The buffer curves of the treated soils are found to be flatter than those of the untreated ones.

ACKNOWLEDGEMENTS

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STUDIES ON LATERITE AND RED SOILS OF INDIA

I. INTRODUCTION

BY

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(Received for publication on 15 January 1940)

LATERIZATION is a common soil-forming process in humid tropics like India, where probably more than one-fifth of the total culturable land belongs to the laterite type. The word 'probably' is inserted deliberately since there has been of late a growing tendency in other countries of classing no longer into the lateritic group many red soils which in the past were taken to be laterite soils. Nevertheless, processes involved in the production of these red soils are intimately connected with laterization.

Both the laterite and the red soils are usually poor in fertility. In view of the fact that these soils occupy such vast areas in India, any research which may eventually lead to their amelioration would seem justified. The Royal Commission on Agriculture in India strongly recommended the carrying out of such investigations.

Apart from practical utility, researches leading to the clarification of 'what is a laterite' are of fundamental scientific interest in this country because the word 'laterite' originated in India. At the present moment there seems to be no definite understanding among pedologists, who have studied such soils in the past, as to the proper definition of this type of soil. Buchanan [1807] first gave the name 'laterite' to surface formations with cellular concretions in Malabar in India. But since then red-coloured soils of the tropics were often designated as laterites [Joffe, 1936]. The researches of Bauer [1898, 1907] brought out the important point that the characteristic feature of the weathering process responsible for the formation of laterites is an accumulation of large quantities of free alumina. This offered an exact chemical index, and efforts followed to evolve a chemical definition of laterite.

The author is of opinion that these efforts were rather unfortunate because instead of clarification they made the issue of defining laterite more confused. The world at large is not likely to accept any of the chemical definitions.

The morphology and chemistry of laterite soils are not yet fully known [Joffe, 1936]. But, whereas the study of the profile characteristics of these soils has progressed considerably in other parts of the world, a detailed bibliography of which is given elsewhere [Robinson, 1932; Harrassowitz 1926], it has not yet received the attention it deserves in India.

The work on the laterite and red soils of India was originally started by the author and his colleagues [Chakraborty and Sen, 1932; 1935] in an attempt to find a method for the mechanical analysis of such soils. A method

in due course was elaborated [Chakraborty, 1935] which with slight modification [Chakraborty, 1936, 1938] was found to be suitable for all types of soil.

For the above work a number of samples of soil were secured from the Directors of Agriculture of several provinces in India as soil samples from the so-called laterite areas in their respective provinces. An opportunity was thus obtained to gain further information on these laterite and red soils of India, and in the next three parts in this series certain physico-chemical measurements made on some of these soils are reported. In the fifth part the chemical definition of laterite soils is discussed. Soils used in these four parts are described in Table I ; these are all surface soils. The sixth part describes the profiles of some of the laterite and red soils of India. Further study of the morphology and chemistry of these soils is in progress the results of which will be communicated for publication in due course.

TABLE I

Locality, colour, organic matter, moisture in air-dry soil, lime content and p*H of supposed laterite soils of India*

Lab. No.	Province	Locality	Colour	Organic matter (per cent)	Moisture in air-dry soil (per cent)	Lime content as $CaCO_3$ (per cent)	pH
80	Assam	Satgaon	Light red	1·8	4·2	Trace	5·0
88	Do.	Shillong	Dark brown	6·8	6·3	*Nil*	4·8
78	Do.	Sibsagar	Yellow	0·90	3·1	*Nil*	4·6
38	Bengal	Bankura	Light red	0·30	1·5	*Nil*	6·4
44	Do.	Birbhum	Light yellow with a tinge of brown.	0·60	1·1	*Nil*	6·1
98	Do.	Dacca	Do.	1·30	1·8	*Nil*	5·6
1	Bihar	Giridih	Deep red	0·64	2·9	Trace	7·2
70	Do.	Ranchi	Light yellow with a tinge of brown	0·92	2·3	*Nil*	5·5
11	Do.	Deoghar	Yellowish brown	1·5	2·0	*Nil*	6·7
74	Orissa	Bhubaneswar	Do.	0·90	2·6	*Nil*	6·5
72	Do.	Puri	Light yellow	0·76	2·1	*Nil*	5·6
58	Bombay	Kumata	Red	2·40	5·6	*Nil*	6·0
56	Do.	Belgaon	Dark brown	2·45	6·1	*Nil*	7·4
20	Burma	Insein	Light red	0·80	1·0	Trace	5·3
64	Do.	Tenasserien	Dark brown	4·1	3·0	*Nil*	5·7
60	Do.	Do.	Yellow with a tinge of brown	2·0	4·1	Trace	7·7
90	Do.	Akyab	Light yellow with a tinge of brown	1·1	1·8	*Nil*	6·8
24	Central Provinces	Raipur	Red	1·1	1·9	0·034	7·6
30	Madras	Taliparamba	Dark brown	10·2	6·3	Trace	5·4
34	Do.	Calicut	Red	1·9	4·0	Trace	5·1
32	Do.	Kasuragod	Deep red	1·28	3·4	*Nil*	4·8
26	Do.	Guntur	Do.	0·32	1·4	Trace	7·7

Acknowledgements

The work on the laterite and red soils of India of which this forms the introduction was undertaken by the Chemistry Department of the University of Dacca with financial aid from the Imperial Council of Agricultural Research. My thanks are also due to Mr J. N. Chakraborty for some of the data given in Table I.

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STUDIES ON LATERITE AND RED SOILS OF INDIA

II. CERTAIN PHYSICAL CONSTANTS AND THEIR RELATION TO THE CONTENT AND THE COMPOSITION OF CLAY

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(Received for publication on 15 January 1940)

(With three text-figures)

THE fact that soils exhibit certain characteristic physical properties has led a number of investigators—prominent amongst whom are Briggs and associates [1907 ; 1912] in America, Keen and associates [1921 ; 1928 ; 1930] in England, Coutts [1929 ; 1930 ; 1932] in Natal and Marchand [1924 ; 1931] in Transvaal—to study the properties in detail. In general the observations were that any method based on a particular property of soils gives values which differ from soil to soil depending on the latter's nature, but for a particular soil the value is constant. The latter fact has been seized and attempts have been made to assess the general character of a soil by thus specifying it by a single number. Such methods have been given the name ' single value determinations ', and the numbers ' single value soil constants ', by Keen and Coutts [1928] who have further stressed the importance of introduction of these methods as an adjunct to the modern system of soil classification, and into soil physics.

The physical properties of laterite soils have not been extensively studied. Bennett [1926] has measured the friability and plasticity of some tropical soils and has tried to correlate them with silica/sesquioxide ratio. He finds that the figures for soils having silica/sesquioxide ratio above 2·0 are distinctly different from those in which this ratio is below 2·0. Similarly Hardy [1923] finds low sticky point and comparatively smaller linear shrinkage for soils having low silica/alumina ratio. He [Hardy, 1925] has also found comparatively low swelling coefficients and low cohesiveness for two red soils of lateritic type from Barbados and Dominica. Marchand and Vander Merwe [1926] have determined the volume expansion of the clay fractions of certain Transvaal soils. The values for soils with low silica/alumina ratio were distinctly smaller than the values of those with high silica/alumina ratio. The work of Bennett, Hardy and Marchand thus shows that lateritic soils are characteristically different in their behaviour from soils of high silica/alumina ratio.

In the publication issued by the Imperial Bureau of Soil Science [1932], in which almost all works on laterite soils up to date are summarized, it was

stressed that ' data for the physical constants for soils of a laterite type are scarce '. Physical measurements on a few supposed laterite soils described in the preceding part [Sen, 1941] were made and these are here reported.

Measurements

The following measurements were made :—

1. Hygroscopic coefficient at 50 per cent relative humidity (R)
2. Sticky point (S)
3. Loss on ignition (I)
4. Water-holding capacity (W)
5. Volume expansion (v)
6. Pore space (p)
7. Apparent specific gravity (L)
8. Real specific gravity (P)
9. Saturation capacity
10. Total exchangeable bases

The methods used for the determination are briefly as follows :—

Hygroscopic coefficient was determined by the method used by Keen and Coutts [1928]. The soil was exposed to 50 per cent relative humidity obtained by sulphuric acid-water mixture until constant weight, and then desiccated in vacuum over concentrated sulphuric acid. The loss in weight gave the hygroscopic moisture.

Sticky point was determined by the method used by Keen and Coutts [1928]. The soil is spread into a thin layer on a glass plate and water is added from a jet until the soil is definitely wet. The mass is then worked into a paste with a spatula and finally the soil is kneaded by hand until the soil just reaches the stage at which it no longer sticks to the hand or knife. At this stage it is possible to cut clean through the plastic mass with a knife.

Loss on ignition was determined by heating a weighed quantity of soil in a platinum crucible over a Bunsen flame, till constant weight was obtained.

Water-holding capacity was determined by the method used by Keen and Raczkowski [1921], as modified by Coutts [1930]. As suggested by Marchand [1924] the soil is first passed through a 100-mesh sieve and the portion failing to pass through is crushed with a wooden pestle and then mixed with the soil that passes through a 100 mesh sieve. The box used has approximately the following dimensions : height 1·5 cm., diameter 7 cm., and capacity 30 c.c.

Volume expansion, pore space, apparent specific gravity and real specific gravity were calculated from Keen-Raczkowski box experiments.

Saturation capacity was determined by the method used by Pierre and Scarseth [1931]. 10 gm. of soil were leached with 250 c.c. of normal barium acetate of pH 7·0. The soil was then leached with 250 c.c. of neutral normal ammonium chloride in order to replace barium by ammonium and the excess of ammonium chloride was removed by washing with alcohol. The absorbed ammonia was then determined by distilling with magnesia.

Total exchangeable bases were determined by the method described by Williams [1929]. 25 gm. of soil were leached with $N/2$ acetic acid. 500 c.c. of the leaching were evaporated to dryness and then gently ignited. A

measured quantity of standard hydrochloric acid was then added to the residue and the excess of acid was titrated with standard alkali after filtration, using phenolpthalein as indicator.

The results are given in Tables I and II.

Hygroscopic coefficient, sticky point and loss on ignition

The correlation coefficients obtained by the above values and the clay for the Indian laterite and red soils are given below.

	I	*R*	*S*
C	0·897*	0·891*	0·900*
I	..	0·955*	0·927*
R	..	..	0·878*

* Significant at $P < 0·01$

It will be seen that very high correlations were obtained between all the values ($P < 0·01$). In other words the Indian laterite and the red soils conform to the general rule, viz. the heavy soils have the highest ignition losses, moisture contents and sticky points. The high values of *RI* and *SI* coefficients support Coutts' [1929] contention, who also observed similar high correlations with Natal soils, that an appreciable portion of the ignition loss is due to 'water of combination' in the clay fraction. This 'unfree water' is of course correlated with the water measured by the factors *R* [Keen, 1930] and *S*. A measurement of this unfree water of Indian laterite and red soils is reported in part III of this series.

For further examination of the association between the quantities *C*, *I*, *R* and *S* partial correlation coefficients were calculated and are given below.

R C. I 0·264	*R I. C* 0·779**
R C. S 0·483	*R S. C* 0·386
S C. I 0·414	*S I. C* 0·621*
S C. R 0·540	*R I. S* 0·787**
I C. R 0·340	*R S. I* 0·062
I C. S 0·384	*S I. R* 0·620*

* Significant at $P < 0·05$
** Significant at $< 0·01$

Taking the relation between *R* and *C* it will be seen that the high association between these two quantities is reduced below significance when the influence of either *I* or *S* is eliminated and that this reduction is much greater when *I* is eliminated than *S*. In other words *R* and *I* are very closely correlated, a fact which is further supported by the partial correlation values of *R I. C* and *R I. S*.

Similarly it will be seen that the high association between *S* and *C* is also reduced below significance when the influence of any one of the factors *I* and *R* is eliminated. Here too *S* and *I* are very closely correlated as shown by the partial correlation coefficients, *S I. C* and *S I. R*. It must, however, be pointed

TABLE I

Results of physical measurements on the laterite and red soils of India

Soil serial No.	Province	Lab. No.	Silica/ sesquioxide ratio of clay fraction	Clay (per cent)	Hygroscopic coefficient	Sticky point (per cent)	Loss on ignition (per cent)	Water-holding capacity (per cent)	Volume expansion (per cent)	Pore space (per cent)	Apparent specific gravity	Real specific gravity
1	Madras	30	1·16	48·4	4·3	48·3	23·2	63·0	7·5	54·3	1·07	2·28
2	Burma	64	1·25	19·5	2·1	24·8	9·9	37·4	4·0	43·3	1·33	2·65
3	Bombay	58	1·30	39·4	2·8	35·9	16·0	45·5	7·3	50·1	1·32	2·65
4	Madras	34	1·30	43·8	3·0	34·6	15·4	45·8	7·4	48·8	1·33	2·60
5	C. P.	24	1·39	17·1	2·0	17·2	9·5	25·1	2·0	40·5	1·76	2·96
6	Assam	80	1·62	27·3	1·7	31·0	9·4	39·3	8·0	44·8	1·38	2·50
7	Burma	20	1·76	12·6	0·7	19·5	3·7	26·7	2·3	36·5	1·51	2·38
8	Bihar	1	1·77	21·2	2·2	24·2	5·7	36·5	10·0	39·0	1·47	2·41
9	Bihar	11	1·90	29·2	1·5	18·2	4·8	30·6	10·0	35·5	1·58	2·45
10	Bengal	38	1·96	19·0	1·2	18·3	4·0	26·8	9·0	33·3	1·64	2·46
11	Bengal	44	2·10	9·2	0·7	15·0	2·6	23·7	8·5	30·4	1·71	2·46
12	Madras	26	2·12	12·0	1·0	12·7	3·3	22·0	4·6	32·5	1·78	2·64
13	Bengal	98	2·15	18·4	1·0	24·1	4·7	42·6	2·0	47·0	1·22	2·30
14	Orissa	74	2·16	17·2	1·5	16·4	4·9	29·2	6·7	37·2	1·60	2·55

out that although the elimination of the influence of R brings down the correlation between S and C just below the level of significance, the association between R and S is not very strong as shown by the value of $RS.C$. In fact the values show that the association between R and C, and S and C are much stronger than that between R and S.

Finally, the high association between I and C is also reduced below significance when the influence of either of the factors R or S is eliminated.

Taking all the above results together, it will be seen that the hygroscopic and the sticky point moistures are correlated more closely with I than C. In other words the hygroscopic coefficient and the sticky point of Indian laterite and red soils are largely controlled by the material in the soil that is driven off by ignition. The result therefore does not support the observation made by Keen and Coutts [1928], Coutts [1929], and Keen [1930] that the moisture content in the soil at half-saturation vapour pressure is controlled much more by the clay content as determined in a mechanical analysis, but it does support their observation with regard to the relationship between sticky point and the ignition loss. In fact it would appear from the high correlation between I and R and I and S obtained here that the loss on ignition is a better measure of the colloid content of the Indian laterite and red soils than the percentage of clay.

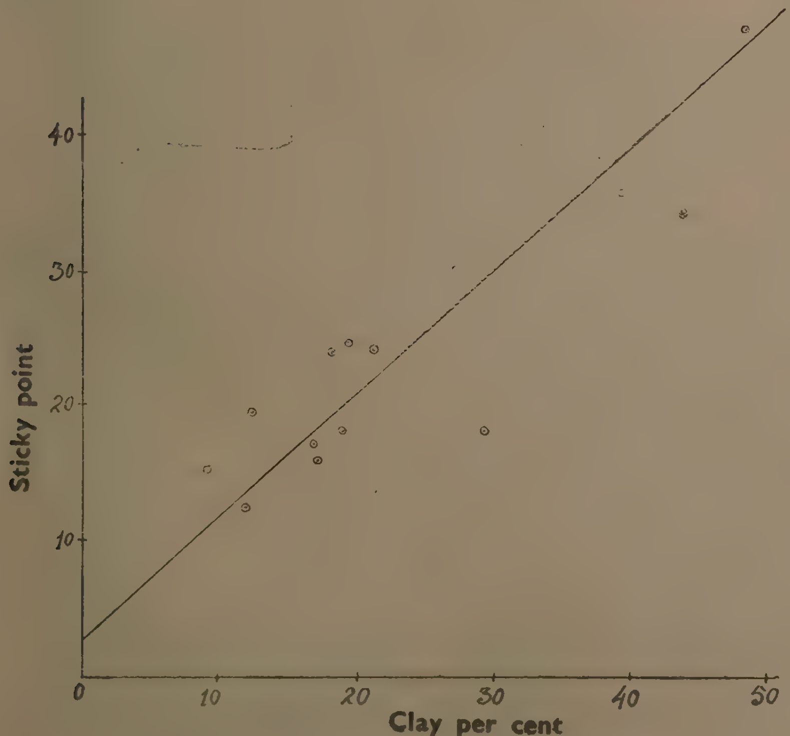

Fig. 1. Relationship between clay and sticky point

In Figs. 1, 2 and 3 the relationships between S and C, I and C, and I and S are shown graphically. The regression equations are as follows :—

$$C = 10{\cdot}78\,R + 4{\cdot}07 \quad \dots \quad (1)$$
$$C = 1{\cdot}1006\,S - 2{\cdot}86 \quad \dots \quad (2)$$
$$C = 1{\cdot}804\,I + 8{\cdot}79 \quad \dots \quad (3)$$
$$S = 1{\cdot}524\,I + 11{\cdot}55 \quad \dots \quad (4)$$

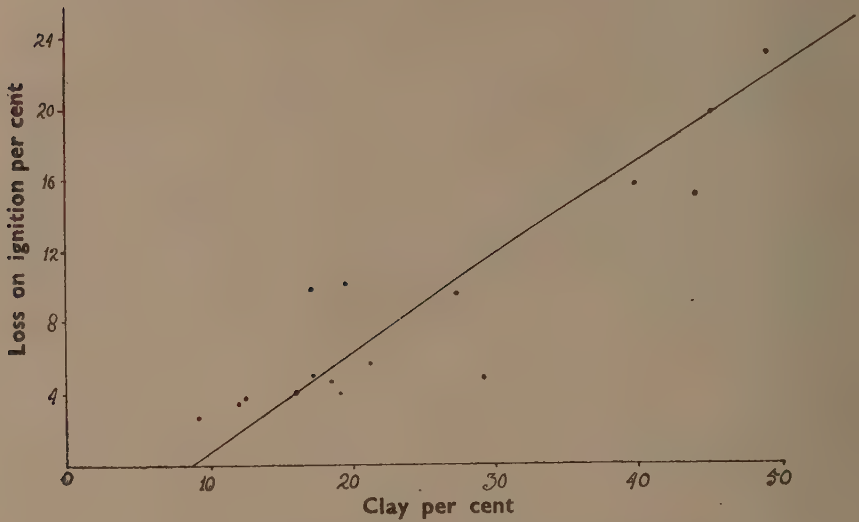

FIG. 2. Relationship between clay and loss on ignition

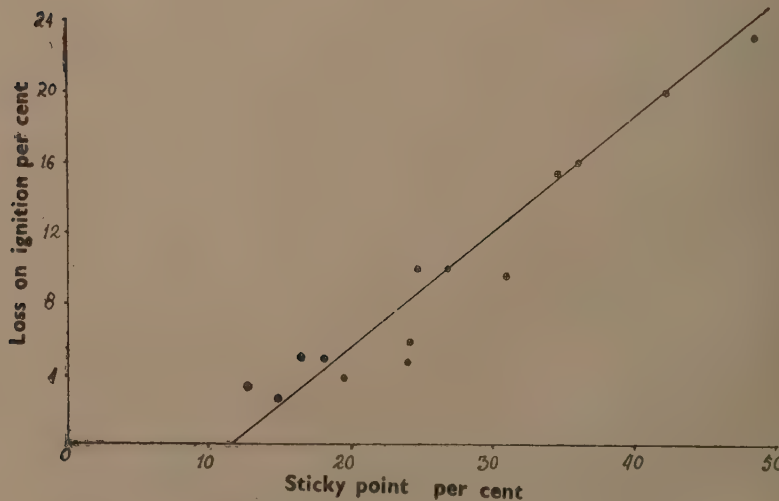

FIG. 3. Relationship between sticky point and loss on ignition

The values in equation (1) are very similar to what were obtained by Coutts [1929], viz. $C = 9 \cdot 1\ R + 4 \cdot 3$ for the tropical soils in Natal, but this was not so for the equation connecting S and I. Coutts' equation for Natal soils was

$$S = 2 \cdot 05\ I + 17 \cdot 6$$

so that when $I = 0$ (i.e. when no colloidal material was present), $S = 17 \cdot 6$. In other words the interstitial water for the Natal soils is $17 \cdot 6$ per cent which confirms the original data (16 per cent) for the interstitial water obtained by Keen and Coutts [1928] for the English soils. Later, however, Keen [1930] obtained the following equation for 250 soils from all parts of the world

$$S = 2 \cdot 91\ I + 7 \cdot 0$$

The interstitial water, i.e. when $I = 0$, is $7 \cdot 0$ per cent and the colloidally held water is roughly $2 \cdot 91$ times the ignition loss. Obviously the interstitial water and, for the matter of that, the order of correlations vary according to soil types.

From equation (4) for the soils examined here it will be seen that when $I = 0$, $S = 11 \cdot 55$. But substituting in equation (2), the value of C when $I = 0$ from equation (3), it will be seen that $S = 10 \cdot 58$. The mean of these two values may be taken as the average value of S when no colloid is present. Therefore for the Indian laterite and red soils :—

(*a*) the interstitial water averages at $11 \cdot 0$ per cent,
(*b*) the colloidally held water is roughly $1 \cdot 5$ times the ignition loss,
(*c*) the amount of colloid is roughly $1 \cdot 8$ times the ignition loss—equation (3),
(*d*) of the clay obtained by the mechanical analysis roughly 9 per cent on an average does not behave as clay—equation (3).

It may be of interest to compare the average values of R, S, I and the imbibitional water of the Indian laterite and red soils with those of a set of English soils containing approximately the same amount of clay. For this purpose the values obtained by Keen and Coutts [1928] for the 14 soils, viz. Nos. 2, 8, 11, 16, 17, 20, 25, 26, 29, 30, 31, 33, 35 and 37 are considered here.

The imbibitional water for the Indian and English soils is approximately $S - 11$ and $S - 16$ respectively.

	Indian soils (average of 14)	English soils (average of 14)	$\frac{\text{Indian}}{\text{English}} \times 100$
C	23·9	23·9	..
R	1·84	2·98	63
S	24·3	35·3	69
I	8·36	7·75	108
Imbibitional water	13·3	19·3	68

The above is self explanatory and shows that the clay of Indian laterite and red soils is roughly 66 per cent as effective as the clay of soils of temperate humid countries in its colloidal behaviour and that the water of combination as indicated by the loss of ignition is higher for the former clay, an explanation for which is given later.

Water-holding capacity (W) *and pore space* (p)

The correlation coefficients obtained between the above values and the clay for the soils investigated here are given below.

$$CW = 0{\cdot}8659$$

$$Cp = 0{\cdot}8164$$

It is clear from above that here too the heavy soils have the highest water-holding capacity and pore space.

The regression equations are as follows :—

$$C = 0{\cdot}9296\,W - 8{\cdot}935 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

$$C = 1{\cdot}367\,p - 32{\cdot}085 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

Coutts [1929] obtained for the Natal soils equal values for W and S ($\overline{W} = 44{\cdot}2$, $S = 44{\cdot}7$) from which he concluded that W and S provide two different methods for measuring the same soil constant. With the Indian laterite and red soils, however, W is greater than S on an average by $11{\cdot}2$ ($\overline{W} = 35{\cdot}3$, $\overline{S} = 24{\cdot}3$). In other words

$$W = S + 11{\cdot}2$$

$$= \frac{S - 11}{R} \times R + 22{\cdot}2$$

$$= xR + 22{\cdot}2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

where

R = hygroscopic coefficient

$S - 11$ = vesicular coefficient according to Wilsdon [1921 ; 1924].

It will be seen that equation (7) is very similar to Briggs and Shantz [1912] equation which according to Wright [1928] reduces to

$$W = xR + 21$$

In other words the Indian laterite and red soils, unlike the Natal soils, maintain the usual water-relationships.

The value $22{\cdot}2$ in equation (7) is the free water in the closely-packed Indian laterite and red soils, while the average vesicular coefficient (x) for these soils is $7{\cdot}2$. According to Hardy [1923] this vesicular coefficient varies according to the different specific nature of the soil colloidal matter and for the west Indian red laterite soils it varies from $2{\cdot}4$ to $3{\cdot}5$, the lowest figure being given by the most typical of these. For the Indian laterite and red soils therefore the vesicular coefficient is remarkably high owing to very low hygroscopic coefficient. The significance of this high value cannot be emphasized until confirmed by more extensive study.

With regard to pore space it will be seen that when $I = 0$, i.e. when no colloid is present, the pore space of the Indian laterite and red soils averages at 30 per cent, a value which is slightly lower than the values obtained by Coutts [1929], viz. 33·5 and Marchand [1924], viz. 34·6, for the Natal and the Transvaal soils respectively.

It may be pointed out here that the mathematical calculations reported above and those which are going to be reported hereafter are interesting in so far as they give an idea of the general behaviour of Indian laterite and red soils, but the calculations are not of much practical value as an aid to identification of a laterite soil since they break down when applied to individual soils in 30-40 per cent of the cases. Similar observation was made by Marchand [1926] in the case of Transvaal soils.

Volume expansion (v), *apparent* (L) *and real* (P) *specific gravities*

The swelling of soil during wetting is obviously a factor of importance from the point of view of the field behaviour of the soil. As a general rule, heavy soils show greater swelling than light ones, and it was suggested tentatively by Keen and Raczkowski [1921] that there should be a close correlation between clay and volume expansion. Both Marchand and Coutts confirmed this, the correlation coefficients being

$Cv = 0{\cdot}87$ for the Transvaal soils

$Cv = 0{\cdot}582$ for the Natal soils

Coutts further observed that for the Natal soils

$Iv = 0{\cdot}817$

$Sv = 0{\cdot}849$

which suggest that v gives a useful measure of the colloid status of the soil in confirmation of the estimate derived from S and I.

The correlation coefficients for the soils investigated here are as follows :—

$Cv = 0{\cdot}0356$

$Iv = 0{\cdot}0912$

$Sv = 0{\cdot}1867$

Not only are the volume expansions of the Indian laterite and red soils very low (Table I) but the above correlation coefficients also show that they bear no relation to the clay or the colloid content of the soils. The behaviour of these soils in respect of swelling therefore appears to be somewhat peculiar.

With regard to the apparent and real specific gravities of the soils the correlation coefficients between these and the clay are

$CL = -0{\cdot}0711$

$CP = -0{\cdot}0132$

No relation therefore exists between the specific gravities and the clay content for the soils examined here. According to Keen and Raczkowski the sp. gravities should vary inversely as the clay content. With the Transvaal soils Marchand, however, obtained no relation between the true specific gravity and the clay content, but he observed that in general apparent sp. gravity decreased with increasing amount of clay. The apparent sp. gr., etc. of the Transvaal soils and those of the Indian laterite and red soils are given below for comparison.

	Transvaal soils	Indian soils
Apparent sp. gravity	1·27 to 1·62	1·07 to 1·78
Real sp. gravity	2·18 to 2·51	2·28 to 2·96
Volume expansion	3·7 to 45	2·0 to 10
Pores pace	33 to 57	30 to 54
Water-holding capacity	22 to 63	22 to 63
Ignition loss	1 to 9	2·6 to 23

Saturation capacity and total exchangeable bases

Saturation capacity and total exchangeable bases together with the degree of saturation and *p*H are given in Table II.

TABLE II

Saturation capacity, total exchangeable bases, degree of saturation and p*H of laterite and red soils of India*

Soil serial No.	Silica/ sesquioxide ratio (clay)	Clay (per cent)	Saturation capacity (per cent)	Total exchangeable bases (per cent)	Degree of saturation	*p*H
1	1·16	48·4	15·1	2·7	17·9	5·4
2	1·25	19·5	7·3	2·0	27·4	5·7
3	1·30	39·4	7·7	5·7	74·0	6·0
4	1·30	43·8	9·6	1·4	14·5	5·1
5	1·39	17·1	5·3	3·9	73·5	6·6
6	1·62	27·3	5·4	0·6	11·1	5·0
7	1·76	12·6	2·5	1·3	52·0	5·3
8	1·77	21·2	8·2	4·6	56·0	7·2
9	1·90	29·2	6·0	3·3	54·0	6·7
10	1·96	19·0	4·8	3·1	64·5	6·4
11	2·10	9·2	2·8	2·7	96·0	6·1
12	2·12	12·0	4·4	4·2	95·0	7·7
13	2·15	18·4	3·6	1·7	47·2	5·6
14	2·16	17·2	6·6	4·5	70·0	5·5

The correlation coefficient between saturation capacity and the amount of clay for the above soils is $0 \cdot 8420 \pm 0 \cdot 0807$. In general therefore the saturation capacity, as may be expected, is greater for the heavier soils. But the correlation coefficient between the total exchangeable bases and the clay is 0·01706. In other words, the total exchangeable bases bear no relation

to the amount of clay. Crowther and Basu [1931] have observed the removal of bases from soils when subjected to the annual leaching over a wide period of years. Obviously therefore the varying leaching conditions, under which the soils under investigation developed, removed the bases and replaced them by hydrogen to varying extent. Consequently a good correlation between the total exchangeable bases and the clay content cannot be expected here. On the other hand the degree of saturation indicates the extent to which the individual soils may have been subjected to leaching. It will be seen that the soils with the low silica/sesquioxide ratios, i.e. the soils which are more leached are generally also more unsaturated. The pH values also show some correlation with the degree of saturation.

It should be pointed out that the saturation capacity of the soils measured here is very poor in comparison with that of the soils formed under humid temperate climates [Robinson, 1932] or that of the Indian dark-coloured clay soils [Puri, 1934]. The maximum and minimum saturation capacities for the Indian laterite and red soils examined here are 15 and 2·5 respectively, whereas the corresponding values for a set of soils of temperate climate are 46 and 14 respectively, or for a set of Indian dark-coloured clay soils are 67·7 and 28·0 respectively.

Composition of the clay

It has already been mentioned that Tables I and II have been arranged according to the silica/sesquioxide ratio of the clay fraction. By this arrangement, as will be seen, high clay values become associated with low ratios and low clay values with high ratios. In fact the correlation coefficient between this ratio and clay is —0·7001 ($P < 0·01$). This association is probably accidental, but it is necessary to bear this in mind so far as the present data are concerned. In view of this correlation it is to be expected that silica/sesquioxide ratio will also be inversely correlated with those physical measurements which are directly influenced by clay. It is necessary therefore to eliminate the influence of clay and calculate the partial correlations which are given below.

Correlation coefficients	Partial correlation coefficients	
MR —0·815** . . .	*MR. C* —0·588*	*M* = Si/sesquioxide ratio
MS —0·744** . . .	*MS. C* —0·3649	*R* = Hygroscopic coefficient
MI —0·857** . . .	*MI. C* —0·726**	*S* = Sticky point
		I = Loss on ignition
MW —0·634** . . .	*MW. C* —0·0781	*W* = Water-holding capacity
Mp —0·727** . . .	*Mp. C* —0·377	*p* = pore space
MN —0·842** . . .	*MN. C* —0·222	*N* = Saturation capacity

* Significant at $P < 0·05$; ** Significant at $P < 0·01$

It will be seen that with the elimination of the influence of clay, most of the relationships between the silica/sesquioxide ratio and the physical measurements become insignificant. Therefore, these physical constants are influenced more by the content than by the composition of the clay. But in the case of loss on ignition, the composition of the clay has a profound influence on it. A low silica/sesquioxide ratio implies a relatively high proportion of ferric oxide and alumina in the soil. Since these oxides generally occur in the hydrated state, one may expect the loss on ignition, or more strictly the water of combination, to increase with a decrease in the ratio. Consequently soils with low silica/sesquioxide ratio will generally have high water of combination as measured by the loss on ignition. This probably explains why the Indian laterite and red soils were found to have higher average loss on ignition than the English soils.

Summary

1. A number of physical constants of laterite and red soils of India have been determined with a view to obtaining data which are practically absent for these soils.

2. It is found that these soils conform to the general rule, viz. the heavy soils have the highest ignition losses, moisture contents, sticky points, etc. Volume expansion, apparent and real specific gravities and the total exchangeable bases, however, bear no relation to the clay content.

3. From a statistical examination of the data it is found that the hygroscopic coefficient and the sticky point are correlated more closely with the loss on ignition than with the clay content. The loss on ignition is therefore a better index of the colloid content of these soils than the percentage of clay.

4. From a comparison of the data for these soils with those for some English soils with the same average clay content it is deduced that these soils have about two-thirds of the colloidal efficiency shown by the English soils. But the water of combination as measured by the loss on ignition is higher for these Indian soils.

5. For the soils examined here the colloidally held water is roughly 1·5 times the ignition loss, and the intersticial water and the vecicular coefficients average at 11·0 per cent and 7·2 per cent respectively. The significance of this high vesicular coefficient cannot be emphasized until confirmed by more extensive study.

6. The soils with low silica/sesquioxide ratios of their clay fraction are generally more unsaturated. The *p*H of the soils also vary with the degree of saturation.

7. The loss on ignition is considerably influenced by the composition of the clay also, the soils with low silica/sesquioxide ratios having the highest ignition losses. The other physical constants are influenced more by the content than by the composition of the clay.

Acknowledgements

The work was carried out under the Dacca University scheme of research on laterite soils with partial financial aid from the Imperial Council of Agricultural Research. Our thanks are also due to Mr J. N. Chakraborty for the figures for clay and the silica/sesquioxide ratio given in Table I.

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STUDIES ON LATERITE AND RED SOILS OF INDIA

III. LOSS OF MATERIALS AT HIGH TEMPERATURE

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(With two text-figures)

IN the previous part [Sen and Deb, 1941] hygroscopic coefficient and loss on ignition of the soils have been determined. Hygroscopic moisture is the water which the colloidal material of the soil will adsorb from water vapour. Besides this there is another water which is constitutionally or chemically combined with the clay. The latter is usually taken to be the water which is not driven at 110°C. but is removed at ignition. It may therefore be calculated as the difference between the loss on ignition of a soil and loss of moisture at 110°C. *plus* the organic matter present in the soil. The works of Robinson and Holmes [1924] and Holmes and Edgington [1930] show that the combined water varies inversely with silica/sesquioxide ratio. Baver and Horner [1933] confirm these results in a general way, finding that the combined water decreases with an increasing ratio. They also suggest that the water loss-temperature curves give some index of the nature of the base-exchange complex. But they seriously question the arbitrary use of 110°C. as representing the temperature at which all adsorbed water is driven off. Harrassowitz [1926] used the amount of combined water in soil to determine the presence of free aluminium oxides. If the water content exceeds 13·92 per cent, which is the amount contained in Kaolin, free Al_2O_3 is taken to be present.

The authors [Sen and Deb, 1941] have also found that the loss on ignition is highly inversely correlated with the silica/sesquioxide ratio of the clay fraction when the influence of clay is eliminated. Since a low silica/sesquioxide ratio implies a relatively high proportion of ferric oxide and alumina which usually occur in the soil in the hydrated state, it follows that soils with low silica/sesquioxide ratio will generally have high water of combination as measured by the loss of ignition.

The loss of matter in soil at temperatures ranging from 50°C. to about 1,000°C. has been determined by Coutts [1930, 1932]. From the trend of the

curves between the temperature and percentage loss he concludes that the loss in the weight of the soil can be mainly ascribed to loss of free and interstitial water up to about 110°C., to loss of organic matter between 110°C. and 250°C., to loss of chemically combined water at higher temperature.

It thus appears that a measurement of the chemically combined water is possible either as the difference between the ignition loss of soil and loss of moisture at 110°C. *plus* the organic matter or as suggested by Coutts. And that such measurements may throw some light not only on the colloidal complex of soils but also on the presence of free sesquioxides in them. In this part the results of investigation on such measurements on laterite and red soils of India will be discussed.

Experimental details

Four soils of varying silica/sesquioxide ratios were selected to include soils of high and low clay contents, organic matter and loss on ignition. About two gram portions of these soils were taken in suitable porcelain boats and were exposed in an atmosphere of water vapour at 50 per cent relative humidity until constant weight. They were then heated in an electric furnace at different temperatures up to 600°C. The temperature was measured by a number of sensitive thermometers giving ranges of temperatures. It was observed that there was a gradual fall of temperature from the centre to either mouth of the furnace tube. This fall was carefully noted. By suitable contrivance the boats were placed on either side of the centre so that maximum fall in temperature from the centre to the furthest end of the boats did not exceed 2°C. The boats were heated to constant weight at each selected temperature.

Experimental results and discussion

In Table I are given the losses at different temperatures of the four soils together with their silica/sesquioxide ratio, clay contents, organic matter and loss on ignition over Bunsen burner.

The figures in the table show that as the temperature increases the loss in soil in all cases also becomes greater until at temperature 550°C.-600°C. no further loss takes place. The total loss at the latter temperature is equal to the loss on ignition over Bunsen burner. Since the ignition temperature over Bunsen burner is about 900°C., it appears that no further change takes place in a soil leading to its loss once it is heated up to 600°C.

It has already been stated that there are two ways of obtaining the combined water (W) in soil. According to Coutts it is

$$W = \text{Ignition loss—the loss at } 250°\text{C.} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

The usual older method is

$$W = \text{Ignition loss—(loss at } 110°\text{C.} + \text{organic matter)} \quad . \quad . \quad . \qquad (2)$$

TABLE I

Percentage losses at different temperatures of soils together with their silica/sesquioxide ratios, clay and organic matter contents and loss on ignition

Soil (Lab.) No.	30	64	80	20
Silica/sesquioxide ratio	1·16	1·25	1·62	1·76
Per cent clay	48·4	19·5	27·3	12·6
Per cent organic matter	10·2	4·1	1·8	..
Per cent loss at—				
110°C.	3·81	1·54	1·36	0·55
130°C.	4·59	2·17	1·66	0·67
150°C.	5·23	2·70	2·14	0·90
170°C.	6·01	3·19	2·73	1·07
190°C.	7·57	4·00	3·35	1·38
210°C.	9·36	5·06	3·97	1·72
250°C.	12·22	6·40	4·68	1·99
300°C.	15·88	7·80	5·35	2·26
350°C.	17·77	8·32	6·92	2·31
400°C.	18·43	8·50	7·20	2·49
450°C.	21·42	9·18	8·40	3·22
500°C.	22·77	9·63	9·22	3·56
550°C.	22·91	9·73	9·33	3·62
600°C.	23·19	9·82	9·38	3·68
Loss on ignition over Bunsen burner	23·21	9·89	9·36	3·67

Let equation (1) be considered first.

Table II shows that W/clay decreases with the increase in the silica/sesquioxide ratio, thus confirming Robinson and Holmes [1924], Holmes and Edgington's [1930], and authors' [Sen and Deb, 1941] observations. Applying Harrassowitz's views that when the percentage of combined water (i.e. W/clay $\times$ 100) exceeds 13·92, which is the amount contained in Kaolin, the presence of free sesquioxide is indicated, it is to be expected that soil 30 should have the largest amount while soil 20 no free sesquioxides. The figures for free sesquioxides given in the last column of the table in a way confirm this. The discrepancy that the clay of soil 20 should contain some free sesquioxide when its combined water is less than 13·92 per cent may be

explained by the fact that all the silicates in the soil are not Kaolin, and secondly in a mixture of such silicates and free sesquioxides the proportions may happen to be such that the amount of combined water may fall below 13·92 per cent, but at the same time soil may contain some free sesquioxides. Therefore the possible method of identification of laterite soils by the use of combined water appears to suffer from the same drawback as does another known method of identification of such soils (dealt with by the authors in Part V in this series) by the use of silica/sesquioxides ratio of the clay fraction. Nevertheless the results obtained above appear to confirm the generalization that temperature up to about 250°C. mainly destroys the organic matter, while higher temperatures destroy the inorganic colloids of the soil.

TABLE II

Combined water (W) *calculated according to equation (1) and* W/*clay in four Indian laterite and red soils*

Soil (Lab.) No.	Silica/ sesquioxide	W	$\frac{W \times 100}{\text{clay}}$	Per cent total free sesquioxide
30	1·16	11·0	20·2	28·5
64	1·25	3·5	17·5	14·2
80	1·62	4·68	16·3	8·7
20	1·76	1·68	13·2	4·4

Let equation (2) be now considered. Here W is taken to be equal to the difference between loss on ignition and the loss at 110°C. *plus* organic matter. In Table III, W is calculated according to this equation.

TABLE III

Combined water (W) *calculated according to equation* (2)

Soil (Lab.) No.	Silica/ sesquioxide	W	$\frac{W \times 100}{\text{clay}}$	Per cent total free sesquioxide
30	1·16	9·20	19·0	28·5
64	1·25	4·25	21·8	14·2
80	1·62	6·20	22·7	8·7
20	1·76	3·12	24·7	4·4

The most striking fact shown in Table III is that the value of W/clay $\times$ 100 is very high even for soil No. 20 containing a small amount of free sesquioxides. Obviously the calculated values of W are larger than what they really should be. This shows that all the adsorbed water is not driven out at 110°C., thus giving increased values for W. Baver and Horner [1933] also found that all the adsorbed water of soil colloids is not removed at 110°C. It is clear therefore that between equations (1) and (2), the former should be employed to find out the combined water in soils.

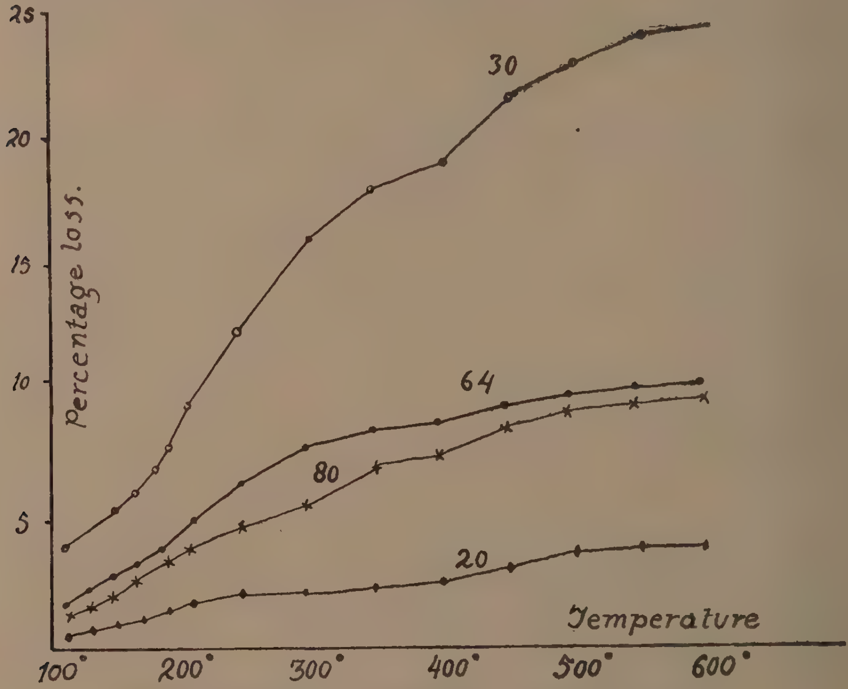

FIG. 1. Percentage of soil materials at different temperatures

In Fig. 1, the percentage loss in weight of soil is drawn against temperature and from the nature of the curves some interesting observations can be made. In all cases the loss increases linearly up to 170° C., when there is a break. From there the loss starts off at a greater rate which, however, gradually goes down until 250°C., when the rate becomes more slow. At 400°C. there is another break with an increased rate of loss which gradually falls off to zero at about 600°C. These increases and falling off in rates will be better understood from Fig. 2 in which rate of loss per 20°C. at different temperatures is given for soil No. 30. For instance the loss between 300° and 350°C. is calculated per 20°C. and plotted against 300°C. in the curve, and so for the other temperatures. The curve shows two distinct maxima, one at 190°C. and the other at 400°C. and three minima at 130°C., 350°C. and 500°C. respectively.

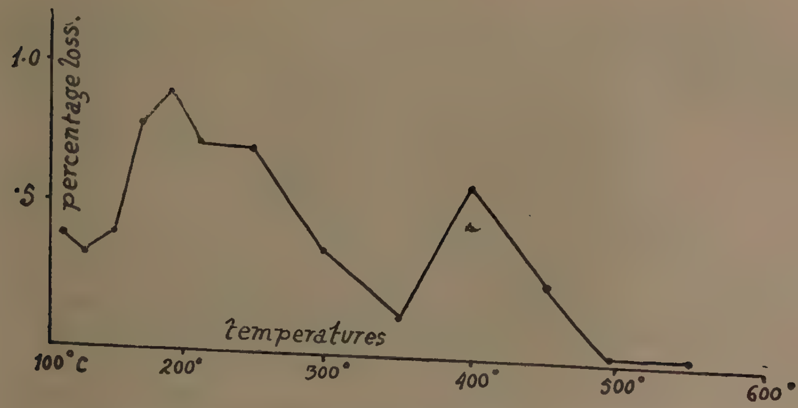

FIG. 2. Rate of loss per 20° rise of temperature of soil materials at different temperatures

The first minima corresponds to the loss of adsorbed water. Upwards of 130°C. destruction of organic matter takes place, the rate becoming maximum between 190° and 210°C. From 250°C. the loss of combined water takes place and as is to be expected the rate falls off until 350°-400°C., when it suddenly jumps up to a maximum. This the authors believe to be due to the shattering of the crystal lattice of the colloidal complex, when a further amount of combined water is exposed for evaporation. Thereafter the rate rapidly falls off until 500°-550°C., when all combined water has disappeared.

SUMMARY

(1) Four Indian laterite and red soils have been tested at different temperatures from 110°C. to 600°C. and the loss in weight of the soils at those temperatures has been determined.

(2) The results show that all the adsorbed (hygroscopic) water is not removed at 110°C.

(3) Upwards of 130°C. the loss is mainly of organic matter and at about 250°C. almost all the organic matter is destroyed.

(4) Upwards of 250°C. the loss is mainly of combined water. At 350°-400°C. the crystal lattice of colloidal complex is broken and further loss of combined water takes place.

(5) Upwards of 550°-600°C. no further loss takes place and the loss at 600°C. is equal to the ignition loss over Bunsen burner.

(6) The combined water given by the loss between 250°C. and 600°C. varies inversely with the silica/sesquioxide ratio of the clay, being larger for the laterite soils of low silica/sesquioxide ratios. When the combined water is calculated for 100 gm. of clay in the soil, a figure is obtained which indicates the presence of free sesquioxide in the soil and may be in a way utilized for identifying laterite soils.

Acknowledgements

The work was carried out under the Dacca University scheme of research on laterite soils with partial financial aid from the Imperial Council of Agricultural Research. Our thanks are also due to Mr J. N. Chakraborty for the figures for clay and the silica /sesquioxide ratio given in Table I.

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STUDIES ON LATERITE AND RED SOILS OF INDIA

IV. THE POTENTIOMETRIC AND CONDUCTOMETRIC TITRATIONS OF INORGANIC COLLOIDS OF LATERITE AND RED SOILS WITH CAUSTIC SODA AND BARYTA

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(With four text-figures)

TITRATION curves have often been used by the chemists in determining the absorptive capacity of colloids. Thus the method has been used with success in the case of proteins by Loeb [1922], Hollman and Godner [1925] and others, and in the case of soil by Hissink [1925], Bradfield [1927] and Baver and Scarseth [1931] and several others.

The absorptive capacity of the clay fraction of some of the Indian lateritic and red soils has been measured by potentiometric and conductometric titrations with baryta and caustic soda and results obtained will be discussed here.

Experimental procedure

The clay fraction (0·002 mm. and below) of the soil was obtained by following the procedure in the usual method of mechanical analysis. The organic matter in the soil was destroyed with hydrogen peroxide, and final dispersion effected with caustic soda. The clay collected by decantation was flocculated with sodium chloride and finally purified by electrodialysis. The purified clay was shaken with water for 6-8 hours and made up to one per cent suspension. Aliquot portions of the suspension were taken for titration with 0·1 *N* baryta and 0·1 *N* caustic soda which were added from micro-burettes. The conductometric titrations were carried out in CO_2-free atmosphere from start to end. For potentiometric titration hydrogen electrode was used.

Results and discussion

Bradfield [1927] has determined the saturation capacity of colloidal clay by various methods. He has come to the following conclusions :—

1. The baryta absorbed at *p*H 7 by an electrodialysed colloidal clay is equivalent to its exchange capacity.

2. The meeting point of two separate straight curves in the conductometric titration of colloidal clay with caustic soda gives the exchange capacity,

3. The caustic soda absorbed by a colloidal clay at pH 7 is less than its saturation capacity. The clay is saturated usually between pH 8 and 8·5 in the case of caustic soda.

4. The exchange capacity of colloidal clay cannot be determined by the conductometric titration with baryta.

Titration curves

In Figs. 1 and 2, the potentiometric and conductometric titration curves with caustic soda and baryta for a few of the clays examined are shown. The general trend of the curves are nearly the same in all cases. In potentiometric titrations it is found that in each case the amount of caustic soda required to raise the clay to any pH is less than the equivalent amount of baryta required to raise it to the same pH.

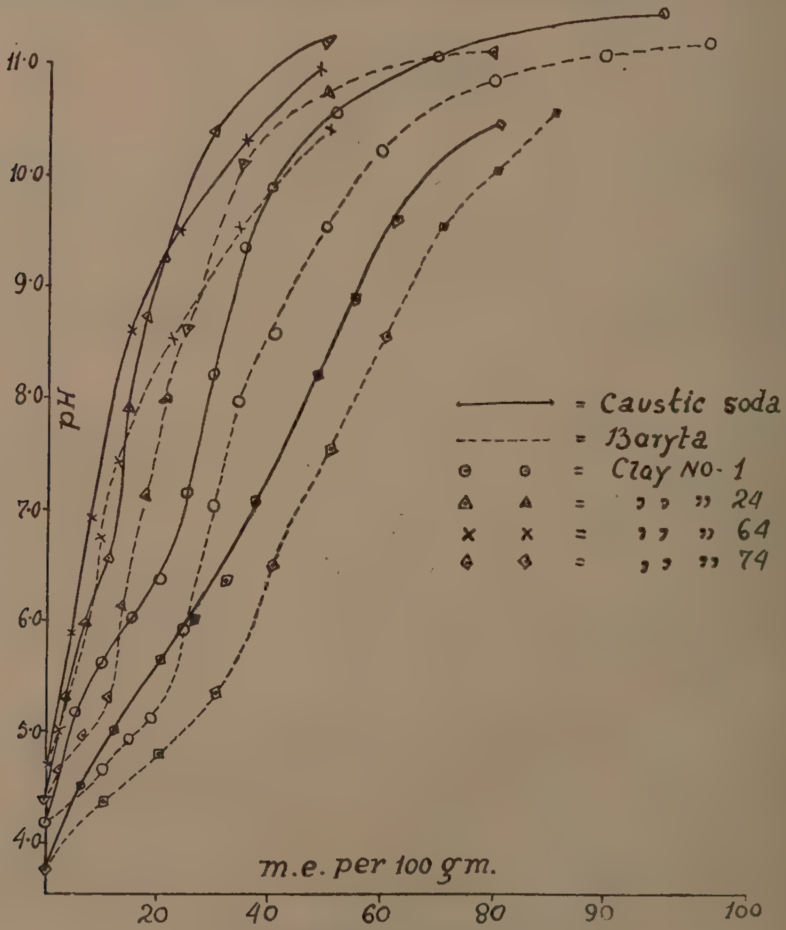

Fig. 1. Potentiometric titration curves of clay

In the case of conductometric titrations with caustic soda the complex formed with Na-ion being dissociable and somewhat soluble, the conductivity of the sol gradually increases with addition of caustic soda until the amount of caustic soda gives a rapid increase in conductivity. A second break in the curves occurs at pH 9·5-10·2 showing further rapid increase in conductivity. This is most probably due to the breaking up of the double bonds of alumino-silicic acid complexes of more soluble substances [Mattson, 1935]. The conductometric titrations of colloidal clay with baryta does not give any indication of its exchange capacity. In some cases the conductivity of the sol slightly diminishes when baryta is added, but in other cases it remains fairly constant until the clays are saturated to an extent of 60-80 per cent, when there is a rapid increase in conductivity.

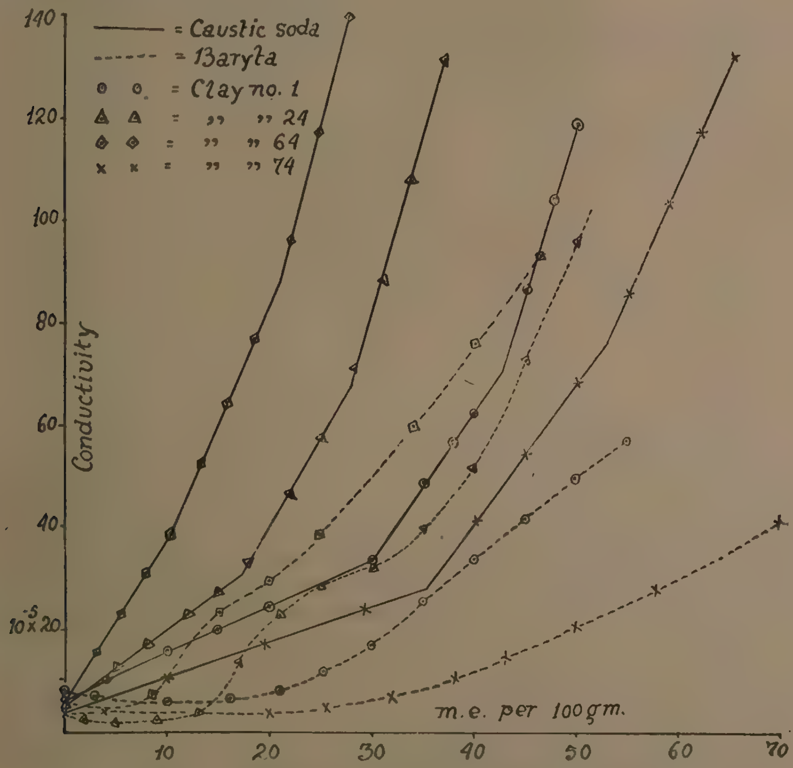

FIG. 2. Conductometric titration curves of clay

EXCHANGE CAPACITY AND ITS RELATION TO SILICA/SESQUIOXIDE RATIO

The exchange capcity by potentiometric titrations with baryta (i.e. baryta absorbed at pH 7) and conductometric titrations with caustic soda are given in Table I. The pH of clay suspension with caustic soda corresponding to the exchange capacity is also given in the table.

TABLE I

Exchange capacity of soil clays obtained by potentiometric and conductometric titrations

*Soil lab. No.	Sample from	Exchange capacity of clay: Potentiometric by baryta at pH 7	Exchange capacity of clay: Conductometric first break in the curves	pH with caustic soda
64	Burma	10·5	10·5	7·8
34	Madras	11·2	11·2	8·2
24	Central Provinces	17·5	17·0	8·4
80	Assam	14·0	14·0	7·8
1	Bihar	30·0	29·5	8·2
38	Bengal	23·0	23·5	8·3
44	Bengal	32·0	31·0	8·3
74	Orissa	44·5	36·0	7·9

*The soils have been fully described in part I in this series [Sen, 1941].

It will be seen from Table I that the potentiometric titrations with baryta and conductometric titrations with caustic soda give almost identical values for exchange capacities excepting clay of soil No. 74. That the base saturation is complete at pH 7 of Ba-clay system is thus supported by a quite different method of finding the exchange capacity, viz. by the conductometric titration with caustic soda. In the case of potentiometric titration with caustic soda, however, the saturation of the clay by this base is not complete at pH 7, but at pH's ranging from 7·8 to 8·4 depending probably on the nature of the clay acids investigated here. No explanation for the variation in the exchange capacity of clay of soil No. 74 by the potentiometric and conductometric titrations can be offered.

In Table II the clays are arranged in order of their silica/sesquioxide ratios showing their exchange capacities and ultimate pH, i.e. the pH of the electrodialysed clay.

Numerous investigators have found that properties of the inorganic soil colloids vary with the silica/sesquioxide ratio. In general Table II shows that as the silica/sesquioxide ratio increases the exchange capacity increases and the ultimate pH of the clay decreases. Thus the exchange capacity of clay of soil No. 64 having silica/sesquioxide ratio 1·25 is 10·5 m.e. for 100 gm.

and 4·68 as its ultimate pH, whereas clay of soil No. 74 having silica/sesquioxide ratio 2·16 has an exchange capacity of 44·5 m.e. and ultimate pH 3·75. The relationship between the silica/sesquioxide ratio and either the exchange capacity or the ultimate pH is not, however, exact. But it may be mentioned that exact relationship is not possible owing to the presence of free oxides of silicon, aluminium and iron as shown by Baver and Scarseth [1931].

TABLE II

Exchange capacity and p*H of the electrodialysed clay*

Clay of soil No.	Silica/ sesquioxide ratio	Exchange capcity by potentiometric titration with baryta (m. e. per cent)	pH of electro-dialysed clay
64	1·25	10·5	4·68
34	1·30	11·2	4·50
24	1·39	17·5	4·35
80	1·62	14·0	4·44
1	1·77	30·0	4·16
38	1·96	23·0	4·30
44	2·10	32·0	4·03
74	2·16	44·5	3·75

When, however, the exchange capacity and the ultimate pH are considered together, it is found that there exists a fairly good inverse relationship between the two sets of values (Fig. 3). It appears therefore that both the exchange capacity and ultimate pH are governed by the same set of factors in the clay.

ABSORPTION CAPACITY AT DIFFERENT pH VALUES

The quantities of baryta and caustic soda absorbed by the clays at different pH are next calculated. A few cases are shown in Fig. 4. These quantities are obtained, following Bradfield, by the difference in the quantities of bace required to raise equal volumes of clay suspension and water to the same pH. The graphs show that there is no precise meaning of the term ' base absorption capacity ' of soil colloids as bases are absorbed continously with increasing pH. Thus clay of soil No. 64 absorbs 10·5 m.e. of baryta at pH 7 and 50·0 m.e., i.e. five times as much, at pH 10·5. Puri and Uppal [1939] have also drawn attention to the necessity of defining the base absorption capacity. The increase in the absorptive capacity above the

saturation pH (i.e. pH 7·0-8·4) is probably due to the breaking up of alumino-silicate complex into simpler silicates and aluminates which remain firmly adhered to the surface of the original complex and may lead to the increase in the absorptive capacity of the clay. It may not be out of place to mention here that there is little or no relation between the quantities of base absorbed by clay at pH's above the saturation point (i.e. pH 7 for baryta and pH 8-8·4 for caustic soda) and the silica/sesquioxide ratios of those clays as shown in Table III

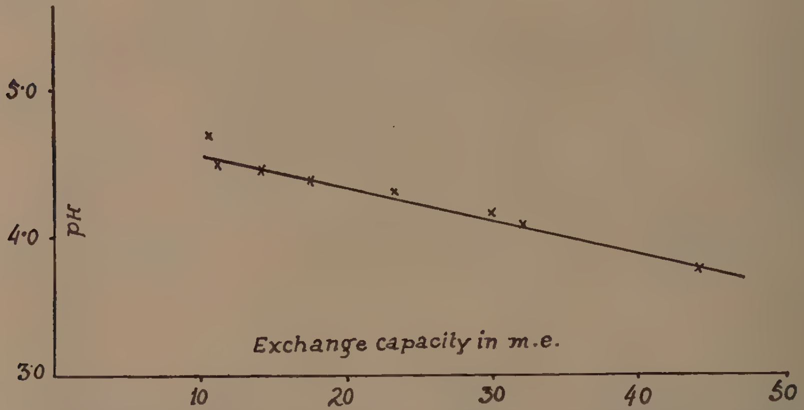

FIG. 3. Relationship between the exchange capacity and pH of the electrodialised clay

TABLE III

Silica/sesquioxide ratios and the absorption of bases by clays at pH *10·5*

Clay of soil No.	Silica/ sesquioxide	Baryta absorbed at pH 10·5	Caustic soda absorbed at pH 10·5
64	1·25	50·0	35·0
34	1·30	36·0	26·5
24	1·39	40·0	26·5
80 . . .	1·62	42·5	28·0
1	1·77	60·0	44·0
38	1·96	43·0	34·5
44	2·10	58·5	52·5
74	2·16	80·5	75·0

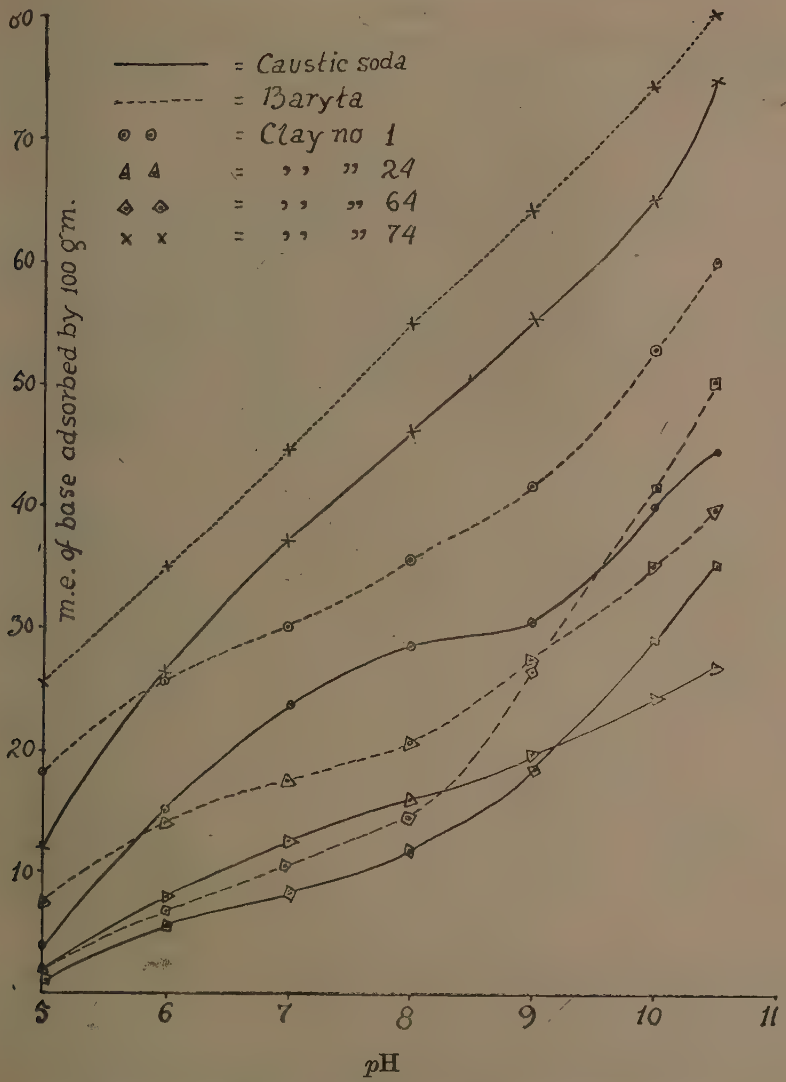

Fig. 4. Absorption of bases at different pH by electrodialysed clay

Percentage base saturation

In Tables IV and V the percentage saturation of the base at different pH's up to the saturation point with baryta and caustic soda respectively are given. They are calculated by the base absorbed (interpolated) at the particular pH, divided by the saturation capacity of the clay, multiplied by 100.

TABLE IV

Percentage saturation of base at different pH values with baryta

Clay of soil No.	*p*H 5·0	*p*H 6·0	*p*H 7·0
64	19·0	62·8	100
34	44·6	80·3	100
24	42·8	80·0	100
80	35·7	71·0	100
1	60·0	85·0	100
38	52·1	93·4	100
44	34·3	84·3	100
74	56·6	77·7	100

TABLE V

Percentage saturation of base at different pH values with caustic soda

Clay of soil No	*p*H 5·0	*p*H 6·0	*p*H 7·0	*p*H 8·0
64	11·4	52·3	78·0	112·0
34	21·4	67·4	84·8	98·2
24	11·6	45·1	71·6	91·6
80	14·2	57·1	80·0	103·0
1	11·6	50·0	80·0	96·0
38	8·7	19·5	86·0	95·6
44	12·5	61·2	93·1	98·4
74	26·6	57·7	82·2	102·2

Tables IV and V show that the base saturation takes place to different extent for different clays at the same *p*H with the same base and for the same clay at the same *p*H with different bases. Thus the base saturation with baryta varies from 19·0 to 60·0 per cent at *p*H 5·0 for the different clays while it varies from 8·7 to 52·1 per cent at *p*H 5·0 for clay of soil No. 38 with caustic soda and baryta respectively. At *p*H 7·0 the clays were saturated from 71·6 to 93·1 per cent with caustic soda. It may be pointed out that percentage saturation is an important factor in crop growth [Pierre, 1931]. The importance of the figures given in these tables is therefore self-evident.

Conclusion

This study was primarily undertaken to see whether the clays of the laterite and red soils of India behaved in any peculiar way so that the peculiarity may be used to characterize these soils. The data obtained, however, reveal no special peculiarity.

Summary

(1) Potentiometric and conductometric titrations have been carried out with electrodialysed clay suspensions of eight Indian laterite and red soils with baryta and caustic soda.

(2) The amount of base absorbed corresponding to pH 7·0 in the case of baryta is taken as the base-exchange capacity of clay. Similarly the amount of base absorbed corresponding to the first break in the conductometric titration curve with caustic soda is also taken as the base-exchange capacity of the clay. The exchange capacities obtained by the two methods are found identical in seven out of eight cases.

(3) The potentiometric titration curves with caustic soda give the exchange capacity at pH's ranging from 7·8 to 8·4 for the clays investigated here.

(4) The conductometric titration curves with baryta are found unsuitable for the measurement of exchange capacities.

(5) The exchange capacity as well as ultimate pH (i.e. the pH of the electrodialysed clay) show a general direct and inverse relation respectively with silica/sesquioxide ratio of the clay, but the exchange capacity bears a more exact inverse relationship with the ultimate pH.

(6) Laterite soil clay absorbs bases continously with increasing pH. A clay may absorb 10·5 m.e. of baryta at pH 7·0 and five times as much at pH 10·5.

(7) There is little or no relation between the silica/sesquioxide ratios and the quantities of bases absorbed above the saturation pH.

(8) The percentage base saturation is different for different clays at the same pH with the same base and for the same clay at the same pH with different bases.

(9) It is thus evident that there is no special peculiarity in the behaviour of the clays of the laterite and red soils of India.

Acknowledgements

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STUDIES ON LATERITE AND RED SOILS OF INDIA

V. THE SILICA/SESQUIOXIDE RATIO OF THE CLAY FRACTION

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OBSERVATIONS as to laterization of rock *in situ* in different parts of the humid tropics have been well summarized by Robinson [1932]. In general the observations were that the minerals in the rock are converted into a yellowish white flaky material surrounding the unweathered rock in concentric layers. If conditions such as water movements are favourable for the removal of iron, the composition of the laterite approaches that of a low grade bauxite ; otherwise, iron accumulates in the crevices formerly occupied by the basic minerals from which it is derived and cements the whole into a characteristic orange-red vesicular rock.

It is clear from the above that laterization is associated with the liberation of free iron and alumina in the weathered material. Soil chemists have tried to utilize this fact in their effort to define soils of a lateritic type. The presence of free alumina in their opinion indicates that the weathering of rocks under laterizing conditions proceeds a stage further than the kaolinite formation, the lowest proportion of silica in combination with alumina. Since weathering is mainly confined to that part of the soil known as the weathering complex or clay, Martin and Doyne [1927] advance the idea that the silica/alumina (molecular) ratio of the clay fraction of a soil below that of kaolinite (2·0) indicates the presence of uncombined alumina. Such soils according to them may be regarded as lateritic. Furthermore, soils whose silica/alumina ratios fall below 1·33 may be regarded as typical laterites.

Some workers prefer to use the silica/sesquioxide ratio to silica/alumina ratio for characterizing laterite, but Martin and Doyne [1927] do not consider iron to be an essential constituent of laterite soils ; on the contrary the inclusion of iron in the ratio will, according to them, make many ferruginous soils formed under temperate climate come under the lateritic group.

Robinson [1928], on the other hand, considers iron to be an essential constituent of soil clay and that its presence in the clay should not be regarded as accidental. In a private communication to one of the authors (A. T. S.) he stressed that silica/sesquioxide ratios should be used as criteria to define Indian laterites. Robinson [1932] thinks that Martin and Doyne's exclusive

choice of alumina for characterizing purposes is too narrow, while Hardy and Follett-Smith [1931] believe that iron oxides play an important part in determining soil properties, such as cohesion and the power of absorbing phosphates.

TABLE I

Percentages of SiO_2, Al_2O_3 in the clay fraction of supposed laterite soils of India

Soils arranged according to the increasing order of silica/alumina (molecular) ratio]

Serial No.	Lab. No. of soil	Soil from	Per cent SiO_2	Per cent Al_2O_3	Per cent Fe_2O_3	Silica/ alumina	Silica/ sesqui-oxide
1	30	Madras . . .	30·09	39·72	8·18	1·31	1·16
2	60	Burma . . .	31·95	38·74	10·84	1·40	1·19
3	64	Do. . . .	31·75	36·85	9·53	1·74	1·25
4	58	Bombay . .	33·30	33·62	15·88	1·69	1·30
5	34	Madras . . .	33·47	33·57	16·20	1·70	1·30
6	32	Do. . . .	35·92	35·93	13·82	1·70	1·37
7	80	Assam . . .	38·59	32·75	12·09	2·00	1·62
8	88	Assam . . .	32·34	27·07	10·52	2·03	1·63
9	24	C. P. . . .	35·47	28·00	23·83	2·15	1·39
10	20	Burma . . .	40·03	31·56	10·99	2·15	1·75
11	70	Bihar . . .	42·44	31·98	10·52	2·25	1·86
12	98	Bengal . . .	45·30	31·87	6·03	2·41	2·15
13	72	Orissa . . .	43·26	30·23	10·99	2·43	1·98
14	78	Assam . . .	43·77	30·20	12·73	2·50	1·95
15	44	Bengal . . .	44·51	30·02	9·52	2·52	2·10
16	1	Bihar . . .	38·71	25·87	17·81	2·54	1·77
17	38	Bengal . . .	43·95	28·89	14·62	2·59	1·96
18	56	Bombay . .	41·99	27·35	16·99	2·60	1·87
19	74	Orissa . . .	45·28	28·11	11·91	2·73	2·16
20	90	Burma . . .	45·82	28·45	9·90	2·73	2·24
21	26	Madras . . .	45·34	26·75	15·08	2·88	2·12

Martin and Doyne [1930] later recognize that some soils (not necessarily tropical) containing much iron have low silica/sesquioxide ratios and a comparatively high silica/alumina ratio and that such soils may have properties similar to those of lateritic soils. They prefer, however, to class these soils as ' pseudo-lateritic ' rather than lateritic since there is no evidence of extremely advance stage of weathering (including presence of free alumina) of which laterite is the outcome.

They recognize further that free alumina may sometimes be present in a part of the clay fraction, while the ratio of silica to alumina in the rest of the clay is sufficiently high to bring up the ratio of the whole fraction to over 2·0. This is a stage which must frequently be found in soils which are gradually laterized. So they modify their previous view and state that a silica/alumina ratio of 2·2 or 2·3 might be regarded provisionally as a suitable upper limit for these soils. According to Shantz and Marbut [1923] such soils are much more abundant than laterite itself.

It should be emphasized that Martin and Doyne's classification is based on the data gathered in the examination of soils in Sierra Leonne. It remains to be seen whether soils with similar silica/alumina ratios (in the clay) from other parts of humid tropics (e.g. India) correspond to those of Sierra Leone. The investigation reported here was carried out with this idea in view.

Soils used in this part have been described fully in part I (Table I) of this series. It may be mentioned here that all the dark-coloured soils became deep red after removal of the organic matter.

In Table I the percentages of silica, alumina, iron oxides of the clay fractions of these soils are given. The table shows that of the 21 soils examined, the clay fractions of only six have silica/alumina (molecular) ratio below 2·0, while those of two soils have the ratio at about 2·0 and the rest have ratios ranging from 2·15 to 2·88. Half the number of soils examined, therefore, do not fall within the class of lateritic or pseudo-lateritic soils as distinguished by Martin and Doyne. On the other hand all the soils with the exception of only five have silica/ sesquioxide ratios in their clay fraction below 2·0. Consequently in the case of 16 soils at least the silica/ sesquioxide ratio indicates the presence of free ferric hydroxide and, by inference, aluminium hydroxide [Robinson, 1932].

Determination of free aluminium and iron hydroxides

Hardy [1931] has developed a method of identification and approximate estimation of sesquioxide components in soils by adsorption of alizarin. The principle underlying the method lies in the fact that iron hydroxide in the fresh state readily adsorbs this dye while aluminium hydroxide does not. On ignition, iron hydroxide loses the capacity to adsorb, while aluminium hydroxide readily takes up the dye. So, by noting the amount of dye adsorbed by the soil before and after ignition, an approximate idea of the amount of free iron and aluminium hydroxides present in the soil may be obtained. Although the method is not very accurate, it is good as a rough test. In Table II the free alumina and iron oxides present in the soils are given.

TABLE II

Percentages of free iron and aluminium hydroxides present in Indian laterite soils

(Oven-dry basis)

Soils arranged according to the increasing order of silica/alumina (molecular) ratio of their clay fractions as in Table I

Serial No.	Lab. No. of soil	Free Al_2O_3 per cent	Free Fe_2O_3 per cent	Total free sesquioxide per cent	Silica/ alumina	Silica/ sesquioxides
1	30	23·5	5·0	28·5	1·31	1·16
2	60	22·4	4·7	27·1	1·40	1·19
3	64	9·2	5·0	14·2	1·47	1·25
4	58	11·7	3·8	15·5	1·69	1·30
5	34	23·2	4·5	27·8	1·70	1·30
6	32	19.3	3·1	22·4	1·70	1·37
7	80	4·6	4·1	8·7	2·00	1·62
8	88	9·3	1·6	10·9	2·03	1·63
9	24	6·8	2·8	9·6	2·15	1·63
10	20	3·3	1·1	4·4	2·15	1·76
11	70	3·4	1·4	4·8	2·25	1·86
12	98	0·76	1·09	1·85	2·41	2·15
13	72	3·2	1·2	4·4	2·43	1·98
14	78	5·3	0·82	6·1	2·50	1·59
15	44	1·1	0·76	1·9	2·52	2·10
16	1	2·4	3·6	6·0	2·54	1·77
17	38	4·1	1·4	5·5	2·59	1·96
18	56	7·4	1·1	8·5	2·60	1·87
19	74	3·1	2·6	5·7	2·73	2·16
20	90	4·5	1·6	6·1	2·73	2·24
21	26	3·3	0.66	3·9	2·88	2·12

It will be seen from Table II that the amount of total free sesquioxdes is high in soils whose clay fractions have silica/alumina ratios below 2·0. Nevertheless free sesquioxides are also present and in some cases amount to 8-10 per cent

of the whole soil, whose clay fraction has silica/alumina ratio distinctly above 2·0, e.g. soils 56 and 24 (serial Nos. 18 and 9 respectively). Most of the above soils can, however, be included into the lateritic group if silica/sesquioxide ratio below 2·0 is taken instead as the upper limit. Still, there are some soils, e.g. soils 74 and 90 (serial Nos. 19 and 20), whose clay fractions have silica/sesquioxide ratio above 2·0, yet they contain 5-6 per cent of free sesquioxides. It appears therefore that if the presence of free hydrated aluminium oxide or free sesquioxides is taken to indicate laterization, nothing but a broad distinction can be made by the use of either silica/alumina or silica/sesquioxide ratio below 2·0. The reason, as has already been stated before, is that free aluminium or sesquioxides may sometimes be present in a part of the clay fraction, while the ratio of silica/alumina or silica/sesquioxide in the rest of the clay is sufficiently high to bring up the ratio of the whole fraction to over 2·0. Further it may be also, as Eden [1929] has obtained evidence with some tea soils of Ceylon, that the ratios higher than 2·0 for soils containing free sesquioxides are due to the presence of finely divided silica (quartz) derived from the parent rock in the clay fraction, a probability not very unlikely in view of silty nature of most of the so-called Indian laterite soils. A third possibility may also be recognized. A considerable proportion of free sesquioxides may occur in the coarser fractions of the soils. They may retain the property of dye adsorption and will thus be detected, while their absence from the clay fraction will tend to increase the silica/alumina or silica/sesquioxide ratios. For example in the soil No. 24 from Raipur, C. P., which contains 17 per cent clay, the amount of Al_2O_3 in the clay as per cent of the whole soil is 4·2 (calculated from Table I), whereas the percentage of free alumina present in that soil is 6·8 (Table II). In other words even admitting the unlikely possibility that all the alumina in the clay fraction exists uncombined with silica, there will be still roughly half as much alumina present in free state in the coarser fractions of the soil and is detected by the alizarin dye.

Finally, it is quite probable that the evidence of laterization may be partially destroyed by resilication in some soils. The possibility of resilication in soils derived from unconsolidated sediments due to concomitant precipitation of silicic acid from river waters has been stressed by Robinson [1928]. The investigations of Mattson [1931] on iso-eletric precipitates demonstrate how such precipitation may take place. Consequently, it is quite possible that resilication has taken place in soils, such as the Dacca soils (soil 98, serial No. 12, Table II) which are alluvial laterite soils. Furthermore, Harrison [1910] says that formation of laterite may occur both in well-drained mountain areas and badly-drained low-lying areas but where the rainfall is intermittent or the drainage poor, laterite may be resilicated by capillary rise of ground water containining silica or silicates in solution, or by a change in the ground water level. The gibbsite previously formed is converted into a hydrated aluminium silicate, principally crystaline kaolin, and the laterite is changed into a red soil.

Considering all these facts, the authors are of opinion that any attempt to evolve precise definition of laterite soils from the silica/alumina or silica/sesquioxide ratio of the clay fraction is not likely to meet with success. The attempt may even mislead the issue. The maximum that can be said in favour of these ratios is that these may serve as convenient checks, but other means must be sought to define a laterite soil. The work of Hardy and

Follett-Smith [1931] shows that the profile of the soil should be examined in every case and in the next part an examination of the soil profiles of some of the laterite areas in India is reported.

Summary

1. Silica/alumina and silica/sesquioxides molecular ratios of the clay fractions and the amount of free aluminium and iron hydroxides by the adsorption of alizarin (Hardy's method) in 21 so-called Indian laterite soils have been determined.

2. The clay fraction of only six soils have silica/alumina ratios below 2·0, while those of the remaining soils have the ratios ranging from 2·0 to 2·8. On the other hand, the clay fractions of 16 soils have silica/sesquioxide ratios below 2·0.

3. The six soils whose clay fractions have silica/alumina ratios below 2·0 contain also fairly large amounts of free alumina and total free sesquioxides. Free sesquioxides are also present and in some cases amount to 8-10 per cent of the whole soil whose clay fraction has silica/alumina ratio distinctly above 2·0.

4. The possibilities of the presence of free sesquioxides in soils whose clay fractions have silica/alumina or silica/sesquioxide ratio above 2·0 as well as the masking of evidence of laterization due to resilication in soils have been discussed.

5. It is stressed that any attempt to evolve precise definition of laterite soils from the silica/alumina or silica/sesquioxide ratio of the clay fraction is not likely to meet with success. The attempt may even mislead the issue.

Acknowledgements

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SEMI-COMMERCIAL TRIALS ON THE MANUFACTURE OF CANNED PEARS (WILLIAMS') AND PEAR JAM AT LYALLPUR

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(With Plate XXXV and one text-figure)

PEARS of very good quality are extensively grown in the Kulu valley (Punjab). The area under this crop can be greatly extended if some satisfactory outlet could be found for this fruit. At present, however, the price realized from sale of fresh fruit in normal years is not enough even to cover its picking and packing charges, as the fruit growers, due to lack of proper storage facilities and the high cost of transport, are unable to market their fresh fruit profitably outside the valley. As a result of this, the best quality fruit sells in the valley at 8 as. to Re. 1 per maund (82 lb.). For the benefit of growers and prospective manufacturers, any suitable outlet for such fruit is, therefore, worthy of consideration.

With this end in view, the present work was undertaken and it embodies detailed results of semi-commercial trials on the canning of pears (Williams' or Bartlett) and pear jam, caried out in a small cannery in the Fruit Section at Lyallpur for a period of three years (1937-39). The cannery with the necessary equipment was installed in 1936 by a special grant given by the Government of India out of Rural Reconstruction Funds for semi-commercial trials on the manufacture of various kinds of fruit and vegetable products.

The principal aim of the investigation was to collect complete data on the cost of production of canned pears. All cull fruit was utilized for making jam and its cost of production was also worked out. It may, however, be mentioned that at present there is not much demand for pear jam in the Indian market.

Material

Preliminary experiments on the canning of pears conducted under the Fruit and Vegetable Preservation Scheme, Punjab, financed jointly by the Imperial Council of Agricultural Research and the Punjab Government had shown that out of the five varieties of pears, viz. Williams', Marie Louise, Beurre Blanc, Doyenné Diette and Napoleon, Williams' was the best canner. In later experiments, pressure tests [Allen, 1929 ; Magness *et al.*, 1929] carried out on Williams' variety indicated that these pears when picked at 13-14 lb,

FIG. 1. Arrival and unpacking of pears at Lyallpur

FIG. 2. Canning of pears as conducted in the cannery

[S=Syruper or the brine tank ; I=Steam inlet to S ; V=Trigger valve for pouring syrup ; C=Can being filled with syrup ; R=Set of can rails ; T=Syrup collecting tundish ; W=Workman taking out the can from the exhauster ; G=Crate for the cans]

pressure and subsequently transported to Lyallpur and stored at 60°-70°F'.' gave the best quality product. On the basis of these results, Williams-pear was picked at Kulu and was subsequently transported to Lyallpur where it was stored until ready for canning.

Consignments of pears for semi-commercial trials

Ordinarily pears from Kulu are sent out in small baskets of 9 lb. capacity costing an anna each. This method when applied to large consignments is naturally very expensive. Only a small quantity of pears during 1937 were got in this manner, while a major portion was received in cone-shaped baskets called *kiltas* (Plate XXXV, fig. 1). Each *kilta* has a capacity of about 60-80 lb. and costs two annas each. It was found that fruit packed in these baskets arrived in excellent condition and, consequently, during subsequent years, this was the only method employed for getting the fruit.

Kulu town is situated about 370 miles from Lyallpur. The 80-mile road from Jogindernagar which is the nearest railway station from Kulu is through a dangerous hilly tract and offers considerable transport difficulties. On this line, freight charges are almost double the normal and this makes it rather difficult for the development of any fruit industry at Kulu. In order to avoid unnecessary injury to fruit and to cut down transport charges to some extent, fruit for our experiment was sent out from Kulu in motor lorries.

In 1937, 64 maunds (Table I) of pears were received in two lots. Much difficulty was experienced in storing the fruit at the right temperature as no suitable arrangements were available. The fruit had, therefore, to be stored at ordinary summer room-temperature ranging from 72° to 108° F. which resulted in shrivelling of the fruit. Only 28 maunds of fruit was found fit for canning and 796 A 2 cans were prepared. Fifteen maunds of shrivelled fruit was used for making 573 lb. of jam (Tables II and III).

Table I

Cost of pears as transported from Kulu to Lyallpur

1	2	3	4	5	6	7	8	9	10
Year	Quantity of pears	Total price of pears at Kulu	Price per md. at Kulu	Cost of packing material (baskets, wrappers)	Labour charges for picking, packing, etc.	Trans-portation charges from Kulu to Lyallpur	Octroi duty at Lyallpur	Total cost at Lyallpur	Cost per md. at Lyallpur
	Mds. sr	Rs. A.	Rs. A. P.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A. P.
1937 .	64 5	57 0	0 14 3	55 0	22 15	205 0	8 0	347 15	5 6 10
1938 .	71 0	53 4	0 11 11	46 12	20 4	225 0	11 2	356 6	5 0 4
1939 .	30 24	17 9 (including picking charges)	0 9 2 (including picking charges)	19 5	6 4 (Packing only)	85 2	4 6	132 10	4 5 4

In 1938, 71 maunds of pears were obtained, a portion of which was canned immediately on arrival as it had attained the desired ripeness. Hard and green fruit was stored at 60°-70° F. in the air-lock of a cold storage plant installed during the course of the year. A fair proportion of the consignment

TABLE II

*Cost of production of canned pears**

Year	1 Size of can	2 Quantity of pears	3 Cost of pears at Lyallpur	4 Quantity of sugar	5 Rate of sugar per md. (82 lb.)	6 Total cost of sugar	7 Quantity of salt	8 Cost of salt	9 Cost of coal	10 Cost of container	11 Cost of labour, labels, excluding supervision charges	12 Total No. of cans prepared	13 Total cost	14 Cost per unit†	15 Percentage of total fruit (Table I) used for canning
		Mds. sr.	Rs. A.	lb.	Rs. A.	Rs. A.	Md. Sr.	Rs. A.	Rs. A.	Rs. A.	Rs. A.		Rs. A.	Rs. A. P.	
1937 . .	A 2	28 0	151 15	336	9 0	36 14	0 16	2 0	15 0	76 1	20 15	796	302 13	0 6 1	43·7
1938 . .	A 2½	21 28	108 15	347¼	10 4	43 6	0 6	0 12	10 8	70 5	21 2	530	255 0	0 7 8	30·6
1939 . .	A 2	8 5	35 3	156½	12 0	22 14	0 3	0 6	7 4	36 10	9 11	366	112 0	0 4 11	26·5

*Cost per tin in 1937 (first year of trial) is high because a good deal of the fruit shrivelled and rotted due to absence of appropriate storage facilities.

TABLE III

*Cost of production of pear jam**

1 Year	2 Quantity of pears	3 Cost of pears at Lyallpur	4 Quantity of sugar	5 Rate of sugar per md. (82 lb.)	6 Cost of sugar	7 Quantity of citric acid	8 Cost of citric acid	9 Cost of coal	10 Labour excluding supervision charges	11 Total cost	12 Jam prepared	13 Cost per lb.	14 Remarks	15 Percentage of total fruit (Table I) used for jam making
	Mds. sr.	Rs. A.	lb.	Rs. A.	Rs. A.	lb.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	lb.	A. P.		
1937 . . .	15 0	81 6	406	9 0	44 9	3¾	5 0	7 0	14 0	152 15	578	4 3	Cost of containers may be added to this	23·4
1938 . . .	24 5	121 3	742½	10 4	92 12	1½	1 14	10 8	15 10	241 14	1,070	3 7	Do.	34·0

*In working out the cost of production fruit that went waste in transport or otherwise has not been taken into consideration. The data given are based on the actual amount of fruit used in these trials.

reached in over-ripe condition and this was utilized for making jam. The total amount of fruit used for canning was 21 maunds 28 seers (530 A 2½ cans) and for jam 24 maunds 5 seers (1070 lb. jam) (Tables II and III). About 4-5 maunds of fruit rotted during transport and storage, while the rest was utilized for other experiments.

During 1939, the pear crop in Kulu, due to lack of timely rains, was of poor quality. Out of the 30·6 maunds of pears obtained, only 8 maunds were used for canning (366 A 2 cans). About 9·5 maunds were used for cold storage experiments, 2·5 maunds rotted during transit and storage, and the rest of the fruit (being of inferior quality) was either sold locally or used for other experimental work.

Cannery

The canning experiments were conducted in a cannery istalled in 1936 by a special grant of Rs. 15,000 from the Government of India, Rural Development Funds. The canning unit was supplied by Messrs Mather and Platt of

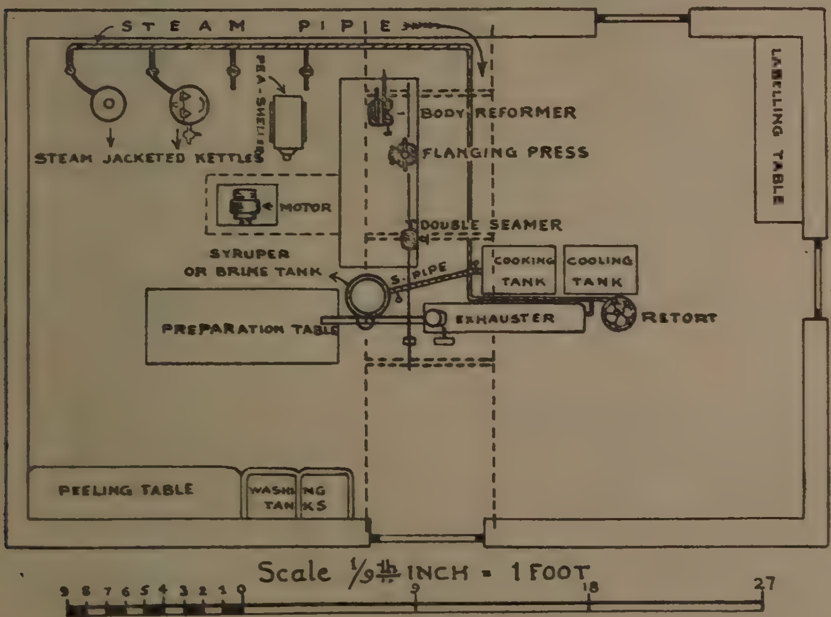

Fig. 1. Lay-out plan of cannery

Calcutta at a cost of Rs. 2,400 and it essentially consists of one water exhaust, one syrup tank of about 50 gallons capacity, one cooling and one cooking tank (Fig. 1). Apart from these, there is a reforming machine, a flanger and a double seamer which were purchased from Messrs Metal Box Co. Ltd., Calcutta, at a cost of Rs. 1,400 (Plate XXXV, fig. 2). To minimize the cost of containers, these were purchased flat and were later reformed.

Experiments

Canning

Fruit fit for canning was first washed in running water, peeled, cut into halves, cored, graded and packed in either A2 or A2½ cans using cane sugar syrup of 40° brix. Only fancy grade fruit was packed. The A2 and A2½ cans were given a process of 20 and 25 mins. respectively, in boiling water and were immediately cooled. Due to high summer temperature, it was found necessary to use ice for the cooling tank. Finished cans were kept in a basement store where the temperature ranges from 70° F. to 95°F. during summer months.

Jam making

Fruit which was unfit for canning was peeled, cored and was either cubed or sliced before boiling in a steam-jacketed kettle with a small quantity of water—when necessary—to soften the pulp. Pure cane sugar was added at the rate of ¾ lb. per pound of pulp and the boiling finished at 221° F. which corresponds to 66 per cent sugar in the finished product. 2-3¾ ounces of citric acid dissolved in a small amount of water was added to every 100 lb. of pulp towards the finish of the boiling. Jam was packed hot (180°-190°F.) in glass jars and cans.

Samples of canned pears and pear jam were sent to Messrs J. Lyons and Co., Ltd. London, who reported as follows (Detailed report on the analyses of canned pears and pear jam is reproduced in the appendix) :—

1. *Canned pears.*—' This is a satisfactory sample of canned pears comparing well with the canned pears usually available in this country '.
2. *Pear jam.*—' This is a satisfactory sample of canned pear jam, but it is not likely to be of interest in England as pear jams have very little sale '.

Cost of production

Details regarding picking, packing, transport, etc. of fruit from Kulu are given in Table I. It will be seen that the cost of fruit actually delivered at Lyallpur worked out to nearly 6-8 times the original purchase price at Kulu, transport charges alone being responsible for a 4-5 fold increase in it. The price of fruit at Kulu varied from 9 annas 2 pies to 14 annas 3 pies per maund, whereas at Lyallpur, the cost per maund came to about Rs. 4-5-4 to Rs. 5-6-10. Further, it will be noted that during 1938-39 incidental expenses were considerably reduced as a result of the experience gained in 1937.

Data for the cost of production of canned pears are given in Table II. It will be seen that the cost of production of an A2 can in 1937 and 1939 worked out at six annas one pie and four annas 11 pies respectively, while in 1938, the cost of an A 2½ can came to seven annas eight pies. It will be seen that the number of cans got per maund of fruit in 1939 was nearly one and a half times that in 1937. This is because the entire lot of peeled fruit was found fit for canning during 1939 while in 1937, due to prolonged storage at high temperature, most of it went waste.

From Table III it will be seen that the cost of jam came to four annas six pies and three annas seven pies per lb. in 1937 and 1938 respectively, the higher cost in 1937 being due to the poor quality of the fruit. The cost of containers has not been included. Jam in these trials was partly packed in one lb. jam jars, each costing two annas five pies and partly in A2 cans costing one anna nine pies each.

In the end, it may be pointed out that a canning factory situated near the fruit-producing area, such as Jogindarnagar, Palampur or even Pathankote, will considerably reduce the cost of production. Further, installation of a plant in a cool place will dispense with storage difficulties which is an important factor to be considered in the manufacture of canned pears.

Acknowledgements

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Summary

1. Details of picking, packing and transportation of Williams' pears from Kulu to Lyallpur and their disposal have been given.

2. The cost of production of canned pears and pear jam has been worked out. The price of pears at Kulu varied from nine annas two pies to 14 annas 3 pies per maund which, when transported to Lyallpur (situated at a distance of of about 370 miles from Kulu), came to about Rs. 4-5-4 to Rs. 5-6-10 per maund, that is, nearly 6-8 times the original price. The price of an A 2 can varies from 4 annas 11 pies to 6 annas one pie and of an A $2\frac{1}{2}$ can is about 7 annas 8 pies. The cost of jam per lb. ranged from 3 annas 7 pies to 4 annas 6 pies. In working out the cost of production, supervision and depreciation charges have not been included.

3. Establishment of a cannery near the centre of production, such as Jogindarnagar or Palampur or even Pathankote, is recommended as it is considered that this will lead to considerable reduction in the cost of production.

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APPENDIX

Report of Messrs J. Lyons & Co., Ltd., London

Canned pears

Wrapping.—The can was wrapped in glacine-type paper

Label.—Pears ; Canned

Fruit Products Laboratories

Punjab Agricultural Department, Lyallpur

Description of container.—Cylindrical tinned can with lapped seam and sanitary seals

Condition of tin.—Slightly stained
Weight of contents.—1 lb. 5 oz.
Weight of pears (drained).—12 oz.
Weight of juice.—9 oz.
Ratio of pears to juice.—1·33 : 1
Condition of pears.—Colour : Slightly darker than usual but satisfactory
Flavour : Satisfactory
Consistency : Satisfactory

Analysis.—Refractometric :	solid content	26·7
Preservatives	sulphur dioxide	not found
	Benzoic acid	,, ,,
	Boric acid	,, ,,
	Salicylic acid	,, ,,
Tin		90 parts per million.

Microscopical examination.—Total count on sugar malt extract agar : less than 10 per gram.

Culture on 3 per cent agar : No mould in 20 c.c.

Summary and general criticism.—This is a satisfactory sample of canned pears, comparing well with the canned pears usually available in this country.

Canned pear jam

Wrapping.—The can was wrapped in a glacine-type paper
Label.—Pears jam
Fruit Products Laboratories
Punjab Agricultural Department, Lyallpur

Description of container.—Cylindrical tinned can, lacquered inside, with lapped seam and sanitary seals

Condition of container.—Excellent, the lacquer being almost unmarked
Weight of contents.—1 lb. 9 oz.
Description of contents.—Flavour : Normal
Colour : Normal
Consistency : Firm and glutinous. The jam contains some small pieces of pear but most of the fruit is in a pulped condition.

Analysis.—Refractometric :	Solids content	72·8 per cent
Artificial colour		not found
Preservatives	Boric acid	,, ,,
	Benzoid acid	,, ,,
	Salicylic acid	,, ,,
	Sulphur dioxide	,, ,,
Tin		,, ,,

Microscopical examination.—Total count on sugar malt extract agar : Less than 10 per gram. Culture in yeast mixture : Sterile.

Summary and general criticism.—This is a satisfactory sample of canned pear jam, but it is not likely to be of interest in England, as pear jam has very little sale.

RESEARCH NOTE

INHERITANCE OF ALTERNATE AND OPPOSITE ARRANGEMENT OF LEAVES IN *SESAMUM INDICUM* DC

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AMONG the 34 unit species of sesamum isolated in the Punjab by Ali Mohammad and Alam [1933], some types have an alternate arrangement of leaves on their plants while in others the arrangement of leaves is opposite. In several inter-varietal crosses made a few years ago with the object of synthesizing better types than those already existing, the arrangement of leaves on the stem was found to be a heritable character. The mode of inheritance of this character does not appear to have been studied by previous workers and the observations recorded here are, therefore, being reported for the first time.

Experimental results

The F_1 progenies of crosses involving alternate and opposite-leaved varieties of sesamum were invariably observed to have alternate arrangement of leaves, showing thereby the dominance of this character over the opposite condition.

In F_2 the segregation of the allelomorphic pair 'alternate and opposite leaves' was studied in eight crosses. The observed and expected frequencies of each phenotypic class in these crosses (Table I) harmonize well with the 3 : 1 segregation, the fit of observed frequencies of various phenotypic classes with those expected according to monohybrid ratio being statistically good in every case. These data, therefore, lead to the conclusion that there is only a monogenic difference between the alternate and opposite-leaved characters in sesamum.

In F_3 the splitting of alternate and opposite-leaved characters was studied in a large number of families of the various crosses under study. According to expectations, all the cultures whose F_2 parents had opposite leaves, bred true to that character, confirming thereby the recessiveness of the opposite-leaved character as outlined above. Out of the alternate-leaved cultures grown in F_3, the number of those which bred true or splitted further like the F_1 plants and the segregation in the latter are shown in Table II.

TABLE I

Data with regard to the segregation of alternate and opposite leaves in F_2 of different sesamum crosses

Cross	Character of parental types with regard to the arrangement of leaves on the plant		Segregation in F_2		Deviation / P. E.	Fit good or not
			Alternate leaved	Opposite leaved		
T22 × T 5A . .	T22 = Alternate .	Observed . .	195	74		
	T5A = Opposite .	Expected on 3 : 1 ratio	201·75	67·25	1·43	Good
T 5A × T22 . .	Do. .	Observed . . .	133	49		
		Expected on 3 : 1 ratio	136·5	45·5	0·90	Good
T 15 × T 5A .	T15 = Alternate . T5A = Opposite	Observed . .	172	60	0·30	Good
		Expected on 3 : 1 ratio	174	58		
T 5A × T 15 . .	Do. .	Observed . .	299	96	0·48	Good
		Expected on 3 : 1 ratio	296·25	98·75		
T 18 × T 5A . .	T18 = Alternate .	Observed . .	67	15	2·11	Good
	T5A = Opposite .	Expected on 3 : 1 ratio	61·5	20·5		
T 5A × T 18 . .	Do. .	Observed . .	408	117	2·1	Good
		Expected on 3 : 1 ratio	393·75	131·25		
T 22 × T 26 . .	T22 = Alternate .	Observed . .	59	14	1·72	Good
	T26 = Opposite .	Expected on 3 : 1 ratio	54·75	18·25		
T 26 × T 22 . .	Do.	Observed . .	62	11		
		Expected on 3 : 1 ratio	54·75	18·25	2·9	Good

Table II

Observed and expected frequencies of true-breeding and splitting alternate-leaved cultures in F_3 and the segregation of the latter with regard to alternate and opposite arrangement of leaves

Cross	Number of alternate leaved cultures		Segregation in splitting cultures		Deviation / P. E.	Fit good or not
	Breeding true	Splitting like F_1 plants	Alternate leaved plants	Opposite leaved plants		
T 22 × T 5A Observed	7	9	312	100	0·52	Good
Expected on 3: 1 ratio	5·3	10·7	309	103		
T 15 × T 5A Observed	4	7	465	157	0·27	Good
Expected on 3 : 1 ratio	3·7	7·3	465	155		
T 5A × T 15 Observed	9	14	2259	695	2·80	Good
Expected on 3 : 1 ratio	7·6	15·3	2215·5	738·5		
T 18 × T 5A Observed	3	4	145	46	0·44	Good
Expected on 3 : 1 ratio	2·3	4·7	143·25	47·75		
T 5A × T 18 Observed	7	15	1918	586	2·77	Good
Expected on 3 : 1 ratio	7·3	14·6	1878	626		
T 22 × T 26 Observed	5	7	279	85	0·71	Good
Expected on 3 : 1 ratio	4	8	273	91		
T 26 × T 22 Observed	6	8	240	72	0·78	Good
Expected on 3 : 1 ratio	4·6	9·3	234	78		

Conclusion

The F_2 and F_3 data presented above establish conclusively that alternate and opposite arrangement of leaves in sesamum are heritable characters, the former being dominant over the latter and the difference between the two being monofactorial.

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